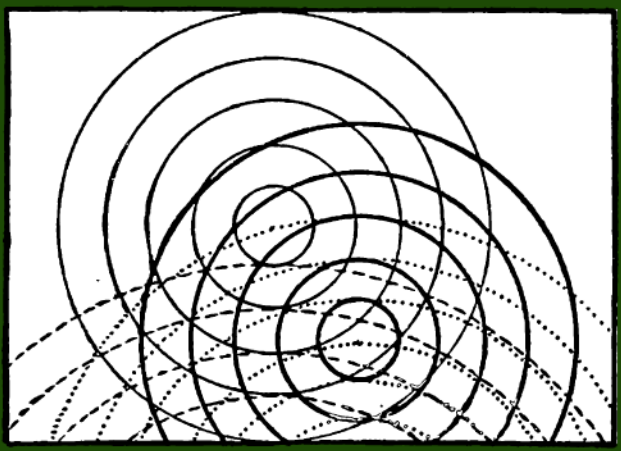
INSIDE THE ATOM

John Langdon-Davies



INSIDE THE ATOM

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BY

John Langdon-Davies

ILLUSTRATED

BY BETTY BARR

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To

Peter and Robin

CONTENTS

Part One

NATURE'S BUILDING-BRICKS 3

Part Two

INSIDE THE ATOM 59

Part Three

WAVES 111

ILLUSTRATIONS

Plate I 50

1. A Photograph Taken in Complete Darkness by the Heat of a Stove
2. Tracks of Alpha Particles
3. Tracks of Alpha Particles

Plate II 124

The Splash of a Drop

Plate III 125

The Splash of a Drop (Cont.)

Plate IV 130

The Story of Waves

Plate V 131

The Story of Waves (Cont.)

PART ONE

NATURE'S BUILDING-BRICKS

Did you know that . . .

nature makes you and everything else in the world out of only ninety-two kinds of building-brick?

if you cut a drop of water into the smallest possible pieces it would cease to be water at all?

every building-brick in your body and in the whole world is madly dancing about and never still for an instant?

the air you are breathing is made of building-bricks moving at least thirty times as fast as the fastest express train?

if you crowded the air in this room close enough together and kept the molecules from moving, it would turn liquid and you could pour it out?

a bicycle tire is just a way of making billions of dancing building-bricks of air bang the road away from you?

every square foot of your body is carrying a weight of 2,000 pounds and more?

when you warm a room with radiators or boil a kettle you are only persuading the dancing building-bricks to dance faster?

every time you use a railway train you are really harnessing the sun to move you?

you can take a photograph in a dark room by the heat of a kettle?

This is the kind of thing you will find explained in the first part of this book.

PART ONE

NATURE'S BUILDING-BRICKS

I. WHAT AM I MADE OF?

For about half a million years now children have been born into the world able to think and ask questions; and sooner or later every one of them has asked the question, "What am I made of?" All sorts of answers have been given to their question and people are still spending whole lives trying to find out more about it. Sometimes the answers have been very absurd.

When I was five I used to go and play in a carpenter's shop and watch the carpenter make things. I saw the things out of which he made strong shiny pieces of furniture, wood and paint and putty and glue and nails and screws. I used to think that heaven must be very like this carpenter's shop and God very like this carpenter, who had only one leg; and I could imagine myself being finished off with paint and glue. It would not have surprised me to be told that there were half-empty paint-pots and glue-pots and wood shavings lying all over heaven.

Now that was a child's answer to the question: "What

am I made of?" but for thousands and thousands of years grown-ups and wise folk all gave just the same sort of answer as this. The whole world thought that mankind was made of dust or mud or sea foam or something like that.

When I was a little boy anybody could make me mad by saying that little girls were made of sugar and spice and all that's nice, but that little boys were made of slugs and snails and puppy dogs' tails; and if a girl said it I would chase her down the road and pull her hair. Yet for thousands of years that was the sort of way in which grown people answered the question; only as a matter of fact they usually thought that men were made of the nice things and women of the nasty!

If you have a younger brother or sister with very childish ideas about such things, you can be pretty sure that once even the wisest man was just as ignorant and childish as he or she.

How did men begin to grow wiser?

II. A QUESTION FOR YOU TO ANSWER

Now I will ask you a question and ask you to think out an answer. It is a very exciting question because of what it leads to. Questions are like roads—they lead to adventure. Most of us would like to follow the road which leads to the North Pole, or the tropical jungle, or the top of Mount Everest, or down the crater of Vesuvius. This question leads farther than any of these and to a more exciting adventure, for when we answer it we are

beginning the adventure of finding out what we are made of.

Take a piece of paper, tear it in two and tear one half in two again and so on. Quite soon you will get a piece so small you cannot tear it smaller. But if you had a microscope and a delicate needle you could go on tearing it smaller and smaller.

Suppose you went on and on like this, would there ever come a time when you had a piece so small that you could not tear it smaller or could you go on tearing for ever?

Or suppose every time you tore the paper in half you became half your own size, too, with more and more delicate fingers and eyesight until you vanished out of ordinary sight as well as the paper? Then you would always feel that the paper was as big as it was to begin with and would have no difficulty at all in tearing it. Could you and the paper go on getting smaller for ever and ever?

Or think of a lake with a boat sailing on it. You could take a glass of water and float a miniature ship on it and they could be just the same as the boat and the lake, only smaller. Then you could dip the tip of your finger into the glass and draw a drop of water out. This again would be just the same, only smaller. From this drop you could draw off a tinier drop still, and so on for a long time. Do you think you could go on for ever and ever, taking a smaller and smaller speck of water and find that it was "just the same, only smaller"?

Or do you think that sooner or later you would find a

speck of water so small that it could not be divided into anything smaller and yet remain water?

Put the question in another way. Here is something white. From the other side of the room it might be milk. But if you come closer you will see that it is flour and made up of tiny grains. Are water and milk and all other things really made up of tiny grains so small that you cannot see them or break them into smaller pieces? Or could things like water be divided up for ever if you knew how?

III. WHAT THE TRUE ANSWER IS

I said that questions are like roads because they lead to adventure. Well, it was only when the old Greeks and Romans began to ask themselves that question that they made the first true step on the adventure of finding out the answer to "What am I made of?"

Even then it took about two thousand years before mankind got really started, for a very strange reason. You have to have the right sort of equipment for any adventure, and mankind left out of the equipment for this one the most important thing of all, experiments.

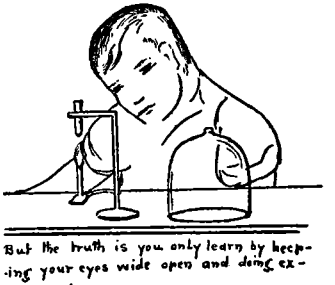
For all that long time even wise men actually thought that they could answer such questions by closing their eyes and sitting back and just thinking it out; when the truth is that you can only answer them by keeping your eyes wide open, getting up, and doing experiments.

Really it was very unfair of me to ask you that question about the tiniest piece of paper or water, for you could not think up the answer, you could only have guessed it,

and it might have taken you two thousand years to see if your guess was true. But instead of keeping you waiting all that time, I will give you the answer now.

Everything in the world—paper, water, your body, the air in this room—is made up of tiniest parts which cannot be broken into smaller pieces without their ceasing to be paper or water or whatever it may be. If you divided up

For two thousand years even wise men thought they could learn about things by closing their eyes and just think-ing it out.



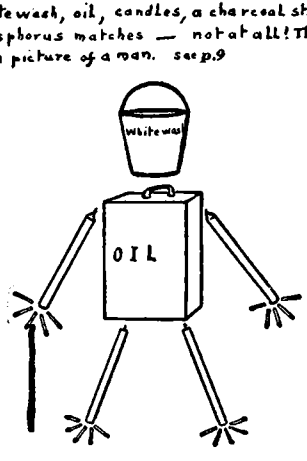
1.

water, for example, you would at last come to the tiniest particle, or molecule, as it is called, of water. You would find that this molecule of water was made of two tiny parts of a gas called hydrogen, which burns very easily, and one part of a gas called oxygen, which you are breathing at the moment. These tiniest parts of hydrogen and oxygen, which together make up the molecule of water, are called atoms.

So that if you went on dividing up water long enough you would come to a time when you would have to choose

between taking hydrogen or oxygen and you would have no water left at all.

These tiniest parts are the building-bricks out of which Nature builds everything in the world. In water there are two kinds of building-brick, and in all the world there



2.

are exactly ninety-two different ones. Out of these everything is built.

We can break up many things into the different building-bricks of which they are made and we can even sort out these bricks and build up other things with them. We know exactly what building-bricks are used in a man's body and we can break up a man's body as a housewrecker breaks up a house, and use the bricks for other things.

Look at this picture of a man. What! There is some mistake! The printer must have put in the wrong picture. You can see only a pound of candles, a box of matches, a can of oil, some whitewash, and some charcoal!

Exactly, but these things are what could be made out of a man's body if the chemist wrecker came along and sorted out the building-bricks and made some useful things of them.

And if this were done you could be sold for a dollar in a dry-goods store.

IV. HOW A WISE MAN GUESSED THE ANSWER

So we begin by knowing the answer to the question about the smallest bit of the paper we tore up together; but we must remember that that answer took thousands of years to discover.

The first step taken by the ancient Greeks and Romans was to decide that if you cut up a thing long enough you would sooner or later come on a piece so small, so hard, so tough that it could not be broken at all. The ancients called such a piece "that which cannot be cut," or "not-cut," which in Greek is "a-tom" or, as we say, atom. Everything is made up of atoms, uncuttable bits, and there are, as we now know, ninety-two different atoms. Out of these ninety-two atoms, her building-bricks, Nature builds everything in the world, including you and me.

Before we talk about these building-bricks as we know them today, it will be interesting to look at some of the wild guesses that men made before they were wise enough to learn the truth. It was a famous Roman, Lucretius,

who wrote a long poem called "On the Nature of Things," in which he said that everything in the world was made of hard, uncuttable atoms. He thought that all these atoms originally flew about all over the universe until one day they all happened to fly in a certain direction and as a result the world and everything in it began.

He thought that all these hard atoms were exactly alike and he had no idea that really every element was made of a different kind of atom. Really he saw them as very, very small grains of dust.

If you have ever watched a dust- or a sand-storm you can easily imagine what Lucretius thought. There he sat one summer day, asking the same old questions, "What am I made of?" "What is everything in the world made of?" and also he asked that other question, "What if you went on cutting things in half for ever? What would be the last piece?" and then he made a guess; you would come to something uncuttable—an atom. Next, perhaps, there came to his mind's eye a picture of a whirling duststorm. "Ah," said he, "that's what happened; all the atoms whirling through space came together by chance as we see them, and that's how the world began. We are like an eddy of dust in a huge storm of atoms."

V. THE NURSERY TALE THAT GROWN-UPS ONCE BELIEVED

How did he know? How could he talk about atoms which were invisible? Lucretius could *not* know about invisible atoms; he was only guessing. Yet human beings were satisfied with it for more than a thousand years, because

humanity had not learned the true difference between guessing and knowing. I will tell you now what this difference is: if Lucretius had been able to do an experiment which proved his guess that these atoms existed, then that would have been knowing. But it was long before the wisest man really understood what was meant by a scientific experiment.

For a very long time the wisest men accepted the idea of an atom without really knowing much about it. They added to it an idea of a great Greek, Empedocles. He said that the true answer to the question, "What am I made of?" was that we are all made of four things mixed in various quantities—earth, water, air, and fire. The difference between you and me, according to him, is that you have more or less of each of these things than I. Another Greek, Hippocrates, the first great doctor, said that in the human bodies these four things—earth, water, air, and fire—took on four shapes—blood, phlegm, black bile, and yellow bile. He said that the whole of your body was made of these four, which sound a little like the slugs and snails and puppy dogs' tails which used to make me mad.

Next they said that all things in nature, including your body and mine, were hot or cold and wet or dry. Thus fire and blood were hot and dry, water and phlegm were wet and cold, earth and black bile were dry and cold, and air and yellow bile were hot and wet.

Now all this, as you can see for yourself, is mere guesswork, but I am telling you about it because for one thousand years and more even learned men believed it to be true. For instance, if you had lived, let us say, a thousand

years ago, in A.D. 933, and got some little illness, the doctor would have come to see you, and he would have tried to cure you according to these strange ideas of Hippocrates. If you were feverish, for example, he would have said, "The patient is too hot and his head feels dry; that is because he has too much of the hot-dry element in him, and that means he has too much blood." And then he would have taken out of his pocket a little box containing a leech, a black wormlike thing you can see on stones in river beds, and he would have put it onto your arm to suck out blood. And he would have gone on having blood sucked out of you until the fever went. Sometimes you would have got better, sometimes you would have died.

Everything about you would have been due to the different amounts of these four things in your make-up; and even today, in the words we still use to describe different kinds of people, we can see proof of how everybody once believed in this sort of answer to the question, "What am I made of?" Thus excitable, hopeful people, the sort we say are optimistic, always hoping for the best, are often called sanguine people from the Latin word for blood, *sanguis*, because in the Middle Ages they were thought to owe their character to having a strong dose of the blood element. We say a person is melancholy when he is sad, and this word means "having black bile," because in those days he would have been thought to have too much of the dry-cold element, black bile.

VI. THE RESTLESS BUILDING-BRICKS

So we can say that for all this long time ideas about medicine and about human character were all based on guess-

work, although it was cleverer guesswork than existed before Empedocles and Hippocrates and Lucretius. At least people had got the idea that each thing, however different it looked from other things, was really made of a few sorts of building-bricks, and that if you could only cut it into small enough pieces you would see that it was so.

This was a great help towards answering the question, "What am I made of?" For suppose everything was as different from everything else as it looks, how hopeless it would be to try and find out how things were made. Suppose you looked at a number of different houses and did not know that, although they looked very different, they were all made of a few kinds of material, wood, bricks, stone, slates, you would think it very hard to make the kind of house you wanted. But directly you saw that all the buildings in the world, however different they seemed, are made of these few materials, you would know how to set about choosing the right sort of material to build the house you wanted.

So with nature's building, your body, a puppy's tail, a tree, earth, the sea, a bottle of Canada Dry, an automobile, are all made up of ninety-two kinds of building-brick, and of these kinds all except about fifteen are not used very often. Water is made of two kinds of building-brick, your body of about twelve, an automobile of fewer.

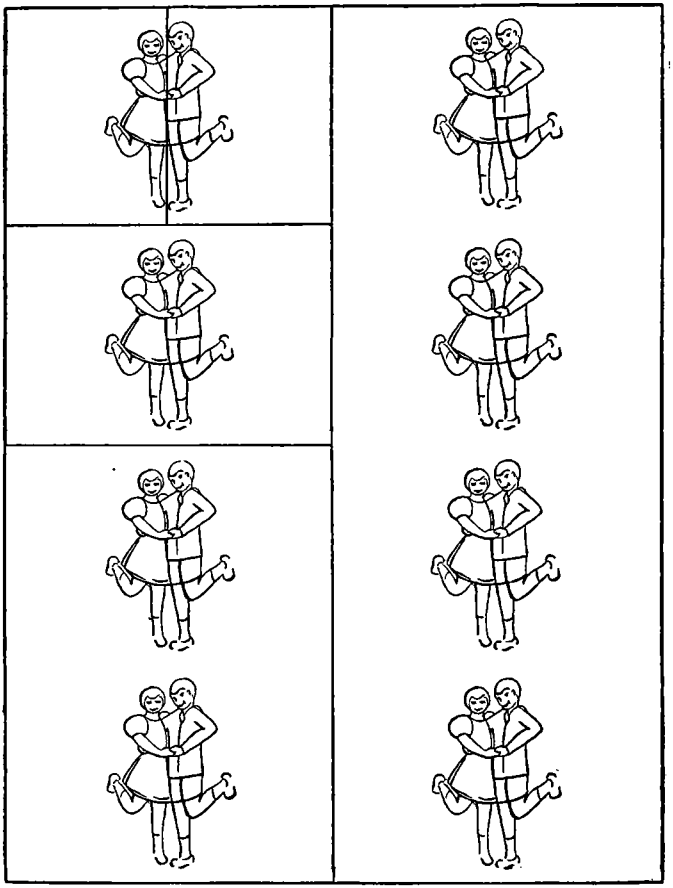
We are going to study these building-bricks, but first of all I want to tell you a very surprising fact about them. Nature's building-bricks are not packed tight together as men's bricks are, but are separated by empty space from one another and they are never for a moment still, but rush about faster than an express train. Your body is entirely

made up of countless billions of invisible little dancing partners madly jazzing around, knocking into one another and never staying still. In fact, if the tiny parts of your body stopped still for an instant you would become colder than you can possibly imagine. Have you ever felt a zero temperature? Long before that you are skating on ice and covering your ears and fingers as warmly as possible. Well, if Nature's building-bricks in your body stopped absolutely still your temperature would be over four hundred degrees colder than zero.

Everything in nature, then, is made up of madly dancing building-bricks. If there was nothing to stop it, a building-brick of air in a room in New York, moving at its usual pace, would reach Chicago in about half an hour. You remember in *Alice Through the Looking-glass* how Alice tried to play croquet with hoops which were soldiers who ran away, and balls which were hedgehogs and ran away, and mallets which were flamingos and ran away, and how difficult it was. Now we find that Nature has to build with bricks moving at a huge pace and out of these bricks even your body is built.

VII. THE SMALLEST DANCERS OUT OF WHICH ALL THINGS ARE MADE

I think it is so astonishing, this idea of everything being made of madly dancing building-bricks, that we had better draw a few pictures. On the opposite page you will find a drawing of eight partners dancing. It is part of a huge dance-hall in which there are thousands of couples dancing, and a curious thing about them is that all the couples are



If you drew anything in nature big enough you would see billions of partners exactly alike. It is the partners that we call molecules and the separate dancers are the atoms.

exactly alike; every boy is like every other boy and every girl like every other girl. It would be a strange ballroom to dance in, for if by any chance some of the partners got separated each boy or girl could join up at once with another partner and never know the difference!

Draw a line down the middle of the page. You have four couples on each side and each side is exactly like the other. Divide the left side in two. You have two couples top and bottom and out of any two couples you could draw the whole picture. Once more draw a line halving the top left corner; now you have only one couple left, but still you know exactly what the whole picture would be from what you have left. Somebody who had never seen the picture could draw it if you gave him this corner piece.

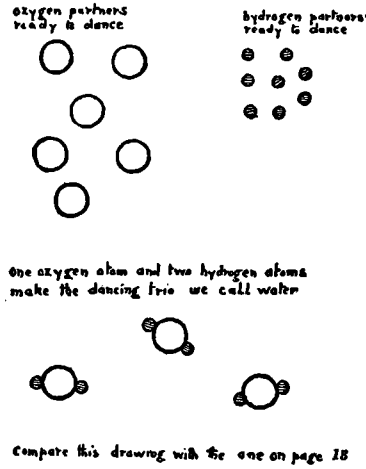
But now divide that in two. No longer is the picture the same on each side of the line; you must choose between a boy and a girl, and if you give a friend one piece he can no longer draw the whole picture.

Now if you drew anything in nature big enough you would see a picture surprisingly like this. You would see billions of couples exactly alike. If you saw one couple you would know all about the whole picture. If you cut up this one couple into the separate dancers you could not know what the original thing was. It is the couples that we call molecules and the separate dancers are the atoms.

Take, for example, a drop of water and imagine it enlarged millions of times. You would find countless dancing couples all exactly alike. In the lower part of picture no. 4 you have three molecules of water dancing together next one another in that vast ballroom called a drop of water.

You will see one great difference between dancing water molecules and dancing humans; whereas we like dancing in pairs, the water molecules like dancing in threes, two light partners called hydrogen and one called oxygen.

If you have a party with one hundred boys and one hundred girls you can be sure of one thing—if they are

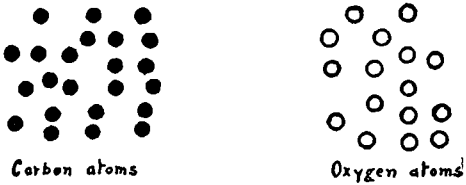

oxygen partners ready to dance
hydrogen partners ready to dance
one oxygen atom and two hydrogen atoms make the dancing trio we call water

Compare this drawing with the one on page 18

4.

put together as partners, one boy to one girl, they will behave in one way; if you put the hundred girls in a bunch without boys they will behave quite differently and the bunch of boys will behave in yet another way. That is the same with Nature's building-bricks. If we have two hundred hydrogen atoms and one hundred oxygen atoms dancing as partners we have water; if the hydrogen atoms dance

about alone without the oxygen partners we have a gas which flies off into the sky, because it is so light, and catches fire if it is given the slightest chance; while if the oxygen


Carbon atoms
Oxygen atoms
Suppose these are in a closed garage with an automobile engine pouring out carbon alone. Some of the carbon atoms take two oxygen partners out of the air like this —
and that is the fizzy gas you drink in ice cream soda; but soon there are not enough oxygen partners left and the rest of the carbon atoms content themselves with one each like this —
and that is the deadly carbon monoxide gas which kills you if you breathe it.
Moral: Leave your garage door open so that the carbon atoms can get plenty of oxygen atoms from the air outside
5.

atoms dance about alone we have the gas which keeps all animals alive by filling their lungs when they breathe.

All the differences in nature depend on what partners the atoms take for their eternal dance. For example, there is

an atom called carbon; when it dances alone it is the coal in our fire; sometimes it catches hold of two oxygen atoms and then the three become the gas which makes soda water fizz. But at other times, when there are not enough oxygen atoms about, the carbon atom is content with one partner and then the two atoms form a molecule of a deadly gas one breath of which will kill you. That is why one should never leave an automobile engine running in a closed garage, for the oxygen in the air may be used up so that the carbon atoms content themselves with one partner and kill you in their dance of death. Strange that the difference between a refreshing drink and death for us is only a question of enough dancing partners in the unending dance of the molecules out of which Nature builds everything. Look at drawing no. 5.

VIII. NOW WHEN I SAY DANCING, I MEAN DANCING

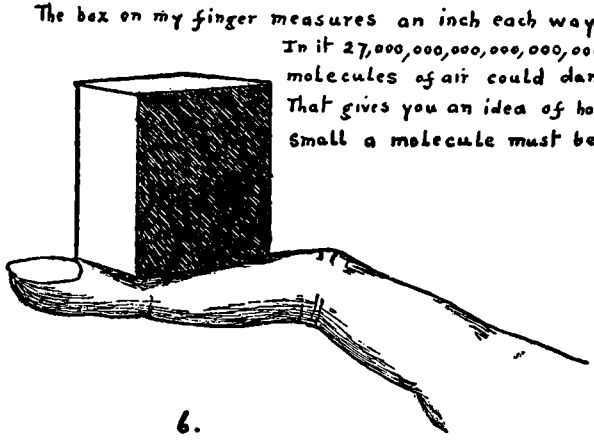
When I was a young boy I used to have to go to dances, but the one I liked best was the last on the program. After all the waltzes and foxtrots and two-steps were over there was a galop. You took a partner and charged. You tried to get to the other end of the room and then you bumped up against the wall, but actually you seldom got there because you were always hitting into other people on the way.

Now that is exactly what molecules are doing all the time. Their favourite dance is the galop. The molecules of air around you at the present moment are galoping in all directions at the rate of six hundred yards a second. Maybe you think they ought all to be dancing out of the window

all the time. But there are so many other molecules of air in the room that it is very rare indeed for any one to succeed in banging up against the walls unless it happens to be squeezed up against the wall to begin with. Actually the average distance a molecule can galop without knocking into the next is a good deal less than one two-hundred-thousandth of an inch. Then there is a collision and the molecule starts off in another direction and almost immediately collides again. The dancing molecules have such a crowded floor space that they collide with other dancers 4,000,000,000 times every second. While you say, "One I'm counting," not too fast and not too slow, every molecule in the air around you, and all over the world, too, has hit into the other molecules four billion times and I am sure they haven't time to say "sorry" before they move on.

And now for two important questions about these dancing molecules. First, how big are they? Second, how many are there in a given space? The molecules of air are of two chief sorts, oxygen and nitrogen mixed in the proportion of one to five. The atoms of oxygen and nitrogen do not join into groups like the two hydrogen atoms and one oxygen atom; they prefer to remain separate and dance with another atom of their own sort. The size of an oxygen atom is less than a ten-millionth of an inch. Nobody can really see how small that is. Perhaps the best way to get some idea is to look at the first joint of your thumb. If an atom were enlarged to be as long as this joint, then the joint would itself have to be enlarged to the length of one hundred and fifty miles.

Then how many dancers are there? If you made a little dance-hall the exact size of this picture, there would be room for 27,000,000,000,000,000,000 molecules to dance, and yet so small are they that there would be ten times as much space between each one as the size of the molecule itself.


The box on my finger measures an inch each way.
In it 27,000,000,000,000,000,000
molecules of air could dance.
That gives you an idea of how
small a molecule must be.

6.

Of course molecules of air can dance in all directions up to the roof, instead of sticking to the floor like human dancers, which gives them more room; but even then it means that in this little box there are twenty-seven billion times as many molecules as there are human beings in the world.

Now I want to show you how all sorts of things which you have seen happening every day can be explained by the dance of the molecules.

IX. SEEING THE MOLECULES DANCE

First of all, though, let us see the molecules dancing. We cannot actually see one molecule, but there are ways of watching a few million of them galoping about at once.

A little more than a hundred years ago a botanist was looking through his microscope at the inside of a plant. He noticed some tiny specks of matter quivering and jogging in every direction. What was making them move? Why didn't they keep still? They were floating in the juice of the plant and they were not alive; they were not swimming of their own will; the table was steady, so that it could not be something outside shaking them. It was very mysterious.

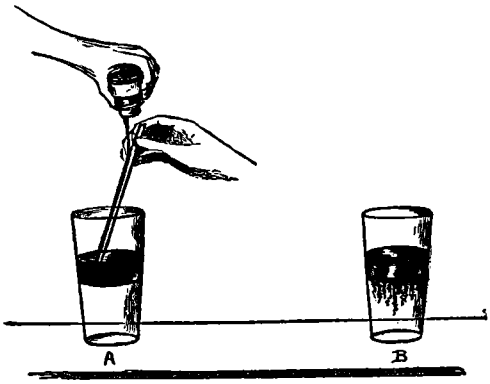
For a long time people thought it might be due to parts of the liquid being a little warmer than other parts. Then some one hit on the right explanation. Perhaps you too have guessed it.

It was the invisible dancing molecules of the liquid butting and banging into the specks and shaking them.

Suppose you were floating quite still on the surface of a small pond and all your friends came and threw hundreds of tennis balls at you from the banks. Each ball that hit you would push you in one way or another; only a little way, of course, but still enough to be detected if, shall we say, a hundred balls pushed at the same time in the same direction. And that is what is happening to the quivering specks; millions of molecules are banging into them all the time, and though they are far too small to be seen, we

know what is happening, because we see the specks quiver at the blows.

So Brownian movement, as it is called, from the botanist, Brown, who first worried his head about it, is a way of seeing invisible molecules dance.



A. Pouring the coloured alcohol gently into the glass of water.
B. A day later the light alcohol molecules have danced their way down in between the water molecules.

7.

But there is another way in which you can see the molecules dancing this very day. Buy a few cents' worth of coloured alcohol and take a glass half full of water. Very gently pour the alcohol on top of the water using a glass rod as in drawing No. 7. You can do this, if you are careful, because the alcohol is lighter than water and therefore rests on top. You have now got two liquids in the glass, the colourless water underneath, and the coloured alcohol on

top. If you have been careful the line between the two is sharp and clear.

Now leave the glass in a place where it cannot be shaken and look at it after a few hours. What do you find? You find the two liquids have mixed. At the bottom is pure water; at the top, pure alcohol, but in between is a layer of liquid lighter in colour than the alcohol above and not as clear as the water below.

What has happened? Nobody shook the glass or stirred it up. Remember that the glass was full of dancing molecules and what has happened is that some of the molecules in the alcohol have banged their way down and slid in between the molecules of water, while some of the molecules of water have banged their way up and pushed in between the alcohol molecules. You are able to see this has happened because of the mixing of the colours. Indeed, this experiment lets you see that even a still glass of liquid is made up of invisible dancing molecules, as we have said.

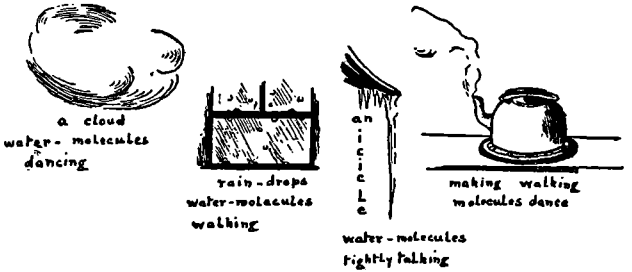
There is an important point about this glass which you should bear well in mind. If you had put the alcohol in first, and then the water, it would not have been a bit surprising had the water pushed through to the bottom, because water is heavier than alcohol and would therefore be bound to fall. It is not the *weight* of the molecules of alcohol that has made them sink into the water. You might just as well expect your weight to help you to jump up into the air as expect the alcohol molecule's weight to help it to sink downwards. The dancing of the molecules is so fast, so powerful, that weight has nothing at all to do with

it; the molecules are able to dance as high upwards or sideways as downwards.

But, you say, they must weigh something; why don't they sooner or later sink down and rest on the bottom of the glass? Why isn't all the air lying flat on the ground instead of dancing madly up and down? We shall see why later; first we must see how every day we interfere with the dancing molecules and make them dance faster or slower as it happens to suit us.

X. WHY ICE MELTS

Go to the ice-box and take a piece of ice. Put it in a saucepan on the fire. First the ice turns to water, then some at



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least of the water turns to steam. What has happened? There is no change in the stuff itself; ice, water, and steam are simply made up of dancing molecules of two hydrogen atoms and one oxygen atom clinging together. What then is the difference between these three things?

Hold a piece of ice in your hand and put on your super-

microscope eyes. Look at the air around—masses of dancing molecules charging around. The air molecules nearest the ice are butting into it. There they go whacking at it millions of times a second. Remember they are not just whacking at a piece of ice; they are whacking at countless billions of molecules. Here comes an oxygen molecule hurtling along at six hundred yards a second bang into our ice molecule.

A fast train moves at about twenty-three yards a second, and if one train smashes into another at that speed the other gets considerably moved. So with the molecules going almost thirty times as fast. The ice molecule is stronger than the train and doesn't smash up under the blow, but it recoils and begins to move very fast, banging into all the other ice molecules near it, until after some billions of bangs in a few seconds the outside ice molecules are all moving fast, and then, as we say, the ice begins to melt.

So that the difference between frozen ice and melting ice is that in the second the molecules have begun to move faster.

We can see what happens when we think of a room full of people. Suppose there are two things the people like; they like to talk to one another and they like to rush about. If they slow down they all get close together and look about for friends. They keep moving, but they are watching the others. Sooner or later they find somebody special they want to talk to and they link arms and talk. They still jump up and down or pull in one direction or other, but they have forgotten the enjoyment of rushing around

in the enjoyment of talking and being close to their friends.

So with molecules; all molecules have two particular pleasures—they love to rush around and they love to meet one another and join on to their friends.

When the pleasure of movement is greatest, so that the molecules just galop, then they make a gas, like the air we breathe, or the gas we burn, or steam. When the molecules are just walking around looking for friends, saying a word here and there, they form a liquid, like water; when they have found their friends and have linked up with them, then they form a solid, like ice.

So ice is a crowd of molecules in which all the molecules have found friends and are talking, holding hands, and hopping about together. Water is the same crowd where all the molecules are walking around separately, enjoying both moving and an occasional word with friends. Steam is the crowd with all the molecules rushing about at a great pace, not talking at all, just dancing.

Evidently they can't do both at once, and if they are doing one they forget about the other. So long as they are rushing about, it never occurs to them to stop and speak, and once they are speaking they will not begin to rush about again until somebody makes them.

XI. HOW OUR BODIES KNOW HOW FAST MOLECULES ARE DANCING

Now how do we human beings tell the difference between when these invisible tiny molecules are talking, walking, and galoping?

How can we stop the molecules talking and make them galop?

We can, of course, tell when the two hydrogen atoms joined to the oxygen atom are talking, walking, and running, for when they are talking we have to eat them; when they are walking we have to drink them; and when they are galoping we have to breathe them. Solid, liquid, gas. Ice, water, steam. Talking, walking, galoping.

But there is another way we can tell. Our bodies are able to feel what the molecules are doing. If the molecules of air in this room are galoping very, very fast we shall say, "Oh, how hot it is today." If they are galoping much more slowly, but still galoping, we shall say, "Oh, it's very cold in here." In short, what we call heat is molecules moving very fast, and what we call cold is molecules moving more slowly.

If we want to heat a thing we must speed up the molecules in it. That is what we do when we put the kettle on the fire. The fire is a special way of making molecules galop. First, the molecules in the air above the fire begin to galop furiously and in so doing bang against the molecules in the kettle bottom, making them join in the dance. Then they in their turn bang into the molecules low down in the water and start them walking faster. Faster and faster they walk, pushed and banged by the molecules in the bottom of the kettle until suddenly some of them start into a galop and, wanting more room, push through the other molecules and rise as steam into the air.

Or take another thing we all know. You come into the room and say: "Oh, how cold it is."

Now you have found out that when you say you feel cold it is only another way of saying that the molecules in your skin have decided that the molecules in the air are not banging into them as often or as hard as they would like.

Well, what's to be done? We've got to stir up these lazy molecules and make them galop far faster. The only way we can do this is to introduce them to some fast galopers and make them bang them about. So we turn on the steam heat. Into the radiator come countless molecules all of them made of two hydrogen atoms and one oxygen atom, dancing madly. They bang into one another but they also bang into the molecules of iron in the radiator. These molecules of iron are very much more serious-minded than the air molecules or the water molecules, and so it takes much more to make them galop. Unless tremendous heat is used they will not even walk about; or to put it in another way, iron does not melt except at a high temperature. But though they cling to one another and so remain solid, the iron molecules pass on the excitement to the air molecules and these galop about more and more violently, until your skin molecules are sufficiently banged and butted, and then you say: "Oh! that's better; the room's warm enough now."

It is a very surprising thing, but you must get used to the idea, that when you say, "I feel cold," you really mean, "Drat those air molecules in this room! They're not dancing fast enough to keep me sufficiently banged and butted!"

XII. HOW WE MEASURE TEMPERATURE

Of course some people like being banged and butted more than others, and so we have found a safer way of measuring heat. We have thermometers.

A thermometer tells us about heat because the dancing molecules have a very special way of showing us how fast they are dancing. The faster they dance the farther they keep from one another. So when we say, "How hot is this room?" we mean, "How fast are the molecules dancing?" and the thermometer tells us the answer in a slightly roundabout way.

Put a saucepan on the fire, filled to the very brim with cold water. You will not have to wait very long before the water will overflow. Why? As the water gets hotter, that is, as the molecules begin to move faster, they part company, they keep farther away from one another, and there is no longer room in the saucepan for all of them.

Now in the thermometer there is a column of a very heavy liquid called mercury. Put the mercury near the fire and the air molecules round about will bang furiously into the mercury molecules, making them dance faster and faster and therefore get farther and farther away from one another. The column of mercury expands, goes higher and higher in its glass tube, and we say, "The temperature is going up."

If we put the thermometer out-of-doors on a cold day, the dancing molecules of mercury will be banging against the molecules in the glass tube, and these against the mole-

cules of air outside, and gradually they will lose their speed in trying to jazz up these sluggish cold ones. The mercury molecules will dance less and less rapidly; they will huddle closer and closer together; we shall see the column of mercury contract and we shall say, "The temperature is going down." We might just as well say, "The molecules are dancing more slowly," but it happens to be easier for us to see that they are huddling closer together.

So it comes to this: all molecules are moving and the faster they move the hotter it is, because heat is just our way of feeling the rapid movements of molecules.

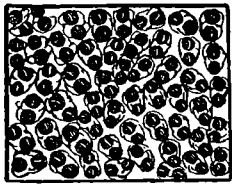
All molecules like to be close together, but the faster they dance the less close do they like to be. They have a special distance that they like to keep from one another, and this distance depends on how fast they are moving. The faster they are moving the farther away they will keep from one another. Of course this is true of the molecules of your own body, so that on a hot day you are larger than on a cold day, unless it is so hot that you get dried up.

But now we must look at what may seem a strange exception to these rules of molecular behaviour. Go to your refrigerator and fill the cubical trays full to the very top with water and allow it to freeze. Use water that is almost freezing to begin with. When the ice is formed you will find that it is taking up more room than the nearly freezing water; it may even be standing above the edge or be hanging over the side of the compartment like icicles.

Surely we would have expected that the colder molecules of the ice would have huddled closer together, so that ice

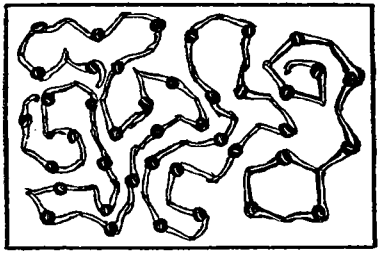
would take up less room than the water. Let us go back to the ballroom again. If all the couples in a ballroom,

All the couples in a ballroom squashed tight, talking, make room for dozens to get in.



9.

but if they were to link arms in a pattern like this there is room for far fewer, that



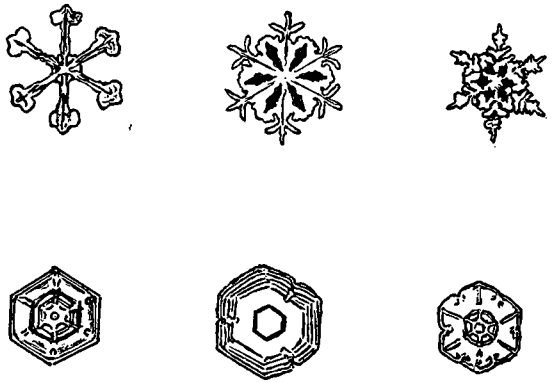
is why ice takes up more room than water.

10.

instead of dancing about, squashed their bodies up tight, we could, of course, get them into a smaller space (Fig. 9). But suppose that they linked arms in a pattern like this,

they might take up more room instead of less (Fig. 10). with closely knit lines of people, and spaces in between,

What has happened with the freezing water is that more and more molecules have huddled closer and closer together as the water got colder, and then at the freezing point they have joined together to form a pattern with spaces in between like a network. That is why ice takes up



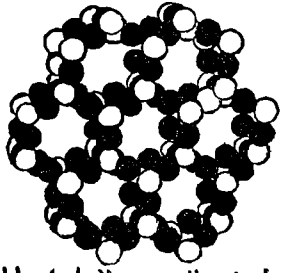
The beautiful patterns made by the molicules of water when they link togther to become snow flakes.

11.

more room than the water out of which it freezes. And that is why water-pipes burst in frosty weather, for the molecules cannot find enough room inside them for the particular pattern they want, so when the water in the pipes expands into ice and needs more room it bursts the pipe to get it.

We can actually see the wonderful patterns the water molecules make when they link arms and dance more slowly. Though they are invisible in the block of ice in the refrigerator, all you have to do to see them is to catch a few falling snowflakes on a dark cloth and look at them

This is a picture of how the molecules of water group themselves when they become ice. You will see the empty spaces between. That is why ice takes up more room than



water. The black balls are the hydrogen partners, and the white ones the oxygen partners.

12.

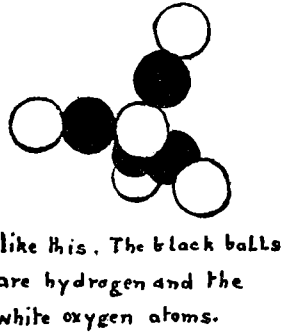
with a magnifying glass. In Fig. 11 you see some of the beautiful patterns of the snow crystals.

In Fig. 12 you see a plan of how the ice molecules lie together: the black balls are hydrogen atoms, the white are oxygen. You see the empty spaces in the pattern. When the ice melts, that is, when the molecules break away from the pattern, these spaces can be filled up, so that the melting water takes up less room than the ice.

XIII. MOLECULES ARE LIKE ELASTIC BALLS

Let us now go back to the question why all the molecules of air do not sooner or later stop dancing and fall, because of their weight, in a heap on the floor.

Take a tennis ball and drop it on the ground. It bounces a few times and comes to rest. Now take two tennis balls

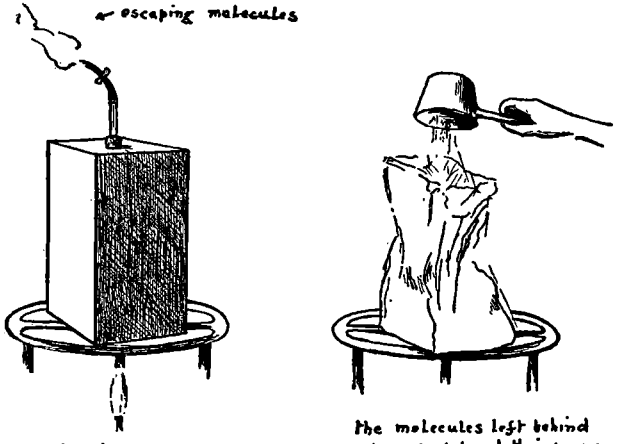


13.

and hang them from pieces of string in such a way that if you pull one string to the side and release it, the tennis ball at the end of it will strike the other one. For a longer time the two balls will bounce into one another and keep moving, but soon they will come to rest.

Now get two ivory billiard balls and hang them in the same way. When you hit one ball with the other, the mov-

ing ball stops dead still and the hit ball swings up almost as far on the other side as the distance through which you let the other one fall, and it will move off at the same speed as the ball which hit it. The two balls will go on hitting and swinging for quite a long time; much longer than the tennis balls.


escaping molecules
pushing the molecules out of the can
the molecules left behind determined to get their proper distance apart pull the walls of their prison in on them

14.

We call this difference between the ivory billiard balls and the others a difference in elasticity. The billiard balls are more elastic than the tennis balls. If the billiard balls went on hitting one another for ever without coming to a standstill, we would say they were perfectly elastic.

Now molecules are perfectly elastic; they never lose speed through banging into one another, so if they reach

the floor under their own weight they will bounce up again immediately. If the floor is not perfectly elastic they may lose weight for a moment, but then the molecules round about will at once whack them up to the right average speed again. For we know that nothing can dance more slowly, that is, stop cold, for long, if everything round is dancing much faster, that is, being warmer. All the molecules in a room will soon insist on moving at the same pace. That is why a cup of coffee gets cold, and why a block of ice melts; all the time everywhere in the universe everything is gradually coming to dance at the same pace; the things that are dancing faster than the average are slowing down, cooling off; the things dancing slower than the average are speeding up, getting warmer.

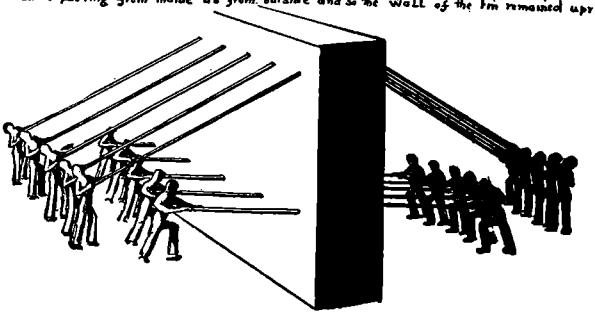
XIV. THE COLLAPSE OF A CAN

Here is a picture of a very simple thing which tells us a great deal about the invisible dancing molecules. It is a tin can with a pipe and tap on top. Into it has been poured a little water and it is being heated on a fire. Soon the water expands into steam and pushes all the air out of the can until there is nothing but steam left inside.

Now the tap is shut off so that no air can get in, the fire is turned out and some ice-cold water is thrown over the tin can. The other picture shows what happens to the can. It has collapsed into a very sorry-looking old wreck, like a tall hat which has been sat on.

Let us try to see what has happened in terms of dancing molecules. First the molecules in the water have been

made to dance faster by the fire. At once they have insisted on keeping a bigger distance between one another. They have pushed out the air molecules through the pipe, and now there are far fewer molecules in the can than to begin with, but at present they are rushing about very fast. Then the tap is turned off to prevent air molecules rushing back and the steam molecules are rapidly chilled, that is, slowed

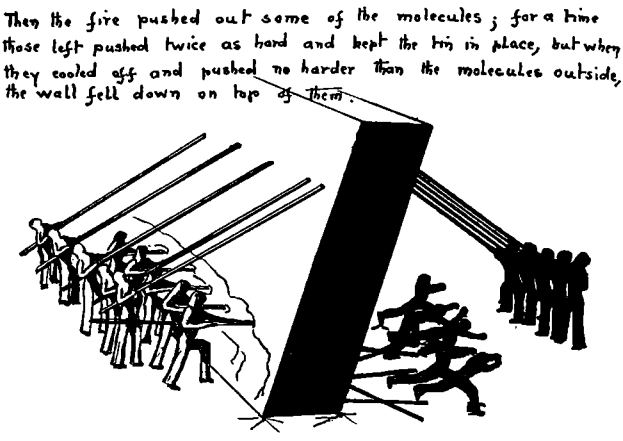

If you imagine each of these little men to be molecules, we have a picture of the tin can before the molecules were pushed out by the fire. There were just as many molecules pushing from inside as from outside and so the wall of the tin remained upright

15

up, so that they want to get closer together; and in order to get closer together they have to pull the sides of the can in on them. Or we can put it in another way: at first, although there are fewer molecules banging the tin can from the inside, they are rushing about so fast that they bang it just as often as the more numerous but less active molecules outside, so the wall stops where it is, banged equally from both sides.

Here is a picture of a wall being pushed by a great

many little men. They are pushing from both sides. If the men on one side stopped pushing, the wall would topple over. What we have seen happen to the can is just the same. To begin with, the can walls have molecules pushing from inside and from outside equally. We say that the air in the can and the air around the can is at the same pressure.


Then the fire pushed out some of the molecules; for a time those left pushed twice as hard and kept the tin in place, but when they cooled off and pushed no harder than the molecules outside, the wall fell down on top of them.

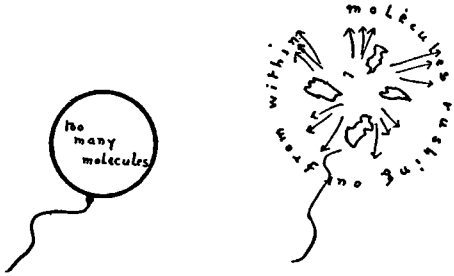
16.

If we heat the can, the air rushes out so that the pressure is still kept equal; and if we closed the tap and heated the can the pressure would get so great inside that the can would burst.

When there are fewer steam molecules than there have been air molecules, the pressure is still the same because, though there are fewer molecules, each one is pushing more often. When we chill them they stop pushing and, like the

wall, the can falls inward. The molecules of the air outside have won the tussle (see Fig. 16).

If the walls of the can had been stronger, there would have been a strange state of affairs inside. All the molecules



The difference between a bursting balloon

and an electric light collapsing

17.

would have been doing their level best to get closer together, but they would have been prevented by the can walls. We call such a state of affairs a partial vacuum. There would be a complete vacuum if there were no

molecules inside the can, but this would be impossible to arrange.

Very often men make a vacuum for some reason or other by sucking out as many of the molecules as they can from inside a can or tube or box. The best-known example is an electric-light bulb. Here the glass bulb has been emptied of a great many of the usual molecules of air. If you take an old used bulb and break it, the exact opposite will happen to what happens when a balloon bursts. The walls of the bulb will fall in, pushed inwards by the molecules from outside, banging their way to make the pressure equal (see Fig. 17).

You can see the opposite by bursting a toy balloon which has been filled too full. Here there are too many molecules *inside*, so that they push the walls of the balloon outward. But always the object of the molecules is to make all pressures equal everywhere.

XV. THE DANCING BUILDING BRICKS IN AN AUTOMOBILE TIRE

There is one more thing about the dancing molecules which explains something you have done or seen done a hundred times.

Remembering what we have seen so far, ask yourself this question: "What happens when an automobile or bicycle tire is blown up?" We say of a flat tire that there is no air in it, but, of course, this is not really true. Wherever air or any other gas can get freely there will always be enough air to be sure that the pressure will be even on all sides, and inside the tire there are just as many mole-

cules galoping and banging up against the rubber as there are outside.

What you do when you pump the tire up is to push inside more molecules so as to increase the bangs. Now when you do that you do something which is, as it were, annoying to the molecules. Molecules are very particular about some things, especially about keeping their distance from one another. If you take an open glass tube you can fill it with air, or water vapour, or hydrogen or oxygen or any other gas, but so long as the temperature is the same and so long as you don't push on the entrance or stop it up, there will always be exactly the same number of molecules in the tube and you will make it overflow if you try to pour more in.

Now when a human being interferes with this pet whim of molecules, one of two things happens. If you take the bicycle pump you can see one of them. Stop up the valve end with your finger and press the pump handle in; then let go the pump handle; it flies up. The molecules have said they are hanged if they will be so close crowded and they just bang the handle away until there is room enough. If you pressed hard enough and the pump were air tight it would burst like a balloon, so angry would the molecules be.

But some things, and among them rubber, have a special way of dealing with the prejudices of the molecules. They do not let them have things entirely their own way; they do not let them have quite the room they want, but they do let them push their walls out so as not to be unbearably crowded.

When we push more molecules into the tire by pumping, the whole crowd does its best to get more room, so as to keep the right distance between the molecules; and, directly they try to do so, they bang up against the rubber tire. Things are very different now with that tire; more molecules are banging it on the inside than on the out and the molecules will not be content so long as this lasts. "Very well," you can imagine the tire saying; "it's very annoying to me to have to use up the energy to expand, but we'll compromise; you shall have a little more room, but not, of course, as much as you want, as I have to think of my own molecules, which are not galoping about like yours, but linked together in serious conversation," and the tire expands.

Soon there comes a point when the tire refuses to give way any more. It has expanded as much as it can without breaking up the linked molecules, and the air molecules for all their bangs have to put up with cramped quarters.

You must stop pumping now, and you know what will happen if you do not. You are now able to ride on air, you have collected a band of banging molecules, which bang and push the hard ground away from you, so that you do not feel it; the tire is just there to keep the molecules in place; it is the air that is important, not the rubber.

And remember another thing. If the day gets hotter those molecules inside the rubber are going to galop more and more wildly, and, therefore, bang the rubber more and more often, and insist upon keeping a greater distance between each molecule; and then the patience of the rubber will end and you will have a burst. You have probably

heard the whoop of triumph when the imprisoned molecules rush out of a bursting tire, to find freedom in order to get the right distance from one another once more.

XVI. LIQUID AIR

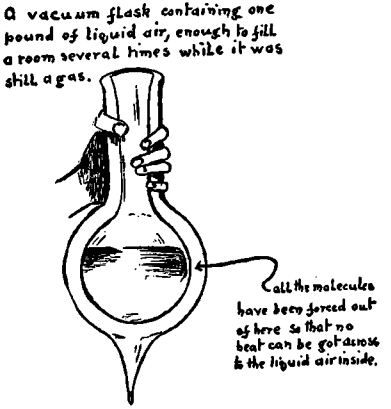
When we squash more molecules than usual into something like a bicycle or automobile tire, the container is polite to them; but what happens if we push them into a container that does *not* say, "Very well; your molecules want more room; I'll give you more room." Such a container had better be careful, because if it is as rude as this and not very strong the molecules will burst it in no time. You will see the sort of answer they will give if you blow up an air balloon beyond the point where it is able to satisfy the demands of the molecules for room.

But suppose we have a strong steel container which is far too strong to give way to molecules, and suppose we press into it quantities of air molecules. Picture to yourself what is likely to happen. The air molecules, oxygen and nitrogen mixed up, want to dance; they do not want to talk to one another, but as more and more arrive in the ballroom dancing becomes impossible; there is such a jam that the best they can do is to move slowly around, chatting to their friends. Their speed is slowed up, and when that happens we know what they must do. The air becomes liquid.

In the picture (No. 18) you will see that I am holding a container within which is a pound of liquid air. You can realize how tightly packed the molecules are when I tell you that in the container there is enough air to fill a room

eight hundred times as big as the container. Every time you breathe you take in only two or three times as much free air as there is liquid air here; so that if the liquid air was free air you could breathe it several hundreds of times.

But please never try to breathe liquid air. Look at Fig. 19 and you will see why. In this little carton there is swim-

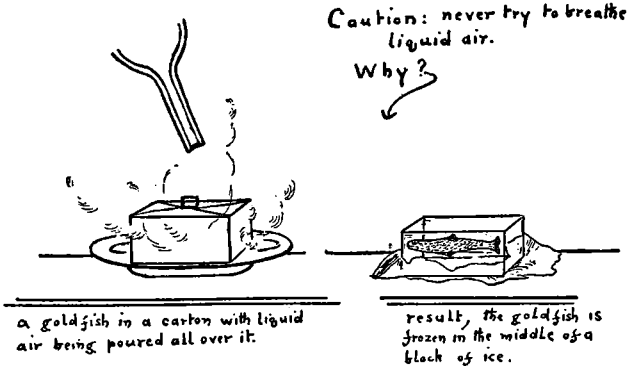

A vacuum flask containing one pound of liquid air, enough to fill a room several times while it was still a gas.
All the molecules have been forced out of here so that no heat can be got across to the liquid air inside.

18.

ming a goldfish. I pour liquid air all round it, and, see, the goldfish is frozen solid in a block of ice. (Don't be worried about the goldfish; I melted it out and it swam away long ago.)

Now why did the goldfish freeze? Remember what happened to those molecules of air; they were slowed down and then kept slowed down by giving them no room to move about. The container is a vacuum flask, so that no

heat or motion comes to jazz them up from outside. When I turned the tap they rushed out and filled the space round the goldfish with slow molecules, that is with cold, for they could not get speed until they had been banged by the other molecules around. Of course, quite soon they were banged into the normal rate of dancing, but before that,


Caution: never try to breathe liquid air.
Why?
a goldfish in a carton with liquid air being poured all over it.
result, the goldfish is frozen in the middle of a block of ice.

19.

they had time to take all the movement from the molecules of water, that is, to freeze the goldfish.

Scientists try to turn all sorts of gases into liquids and even into solids. They have been able to turn the lightest of all elements, hydrogen gas, into a solid lump; and that solid lump of hydrogen is the coldest thing there is. It is so cold that it is nearly as cold as "absolute zero." Absolute zero is the temperature of a thing when all its molecules are completely at rest; even in solid hydrogen the molecules are still moving around, but they are almost still,

compared with the mad dance which they keep up in their ordinary state as a gas.

XVII. MAKING THE MOLECULES WORK

One of the most important things in which men make use of this desire of dancing molecules to keep the proper distance between them is the steam-engine.

Go back to the kettle on the fire. You know from what we have seen that a fire is a special way of bombarding molecules of water so as to make them move so fast that they expand into steam. You know that if you leave the lid on the kettle and it boils violently the lid will jump off. That is what George Watts thought about, as he sat by the fire one day. If the steam moved the kettle lid, why shouldn't it move something useful?

When you want a donkey to move you somewhere you get on its back and hold a carrot in front of its nose. If you want a molecule to move you, you shut it up and hold another sort of carrot in front of its nose. You tell it that if it pushes in a certain direction it will be able to get to the distance it likes from its next-door neighbour. It pushes and you join the thing it pushes to a wheel, the wheel turns, and you go to Chicago at sixty miles an hour.

Or you can put it another way. When I was small, there was a donkey boy who used to come with me on a bicycle when I hired his donkey. If the donkey grew too thoughtful he would ride behind, lift up its tail and rub it against his front tire on the under side. The donkey stopped thinking for about a quarter of a mile each time.

Just as the way to hold a carrot to a molecule's nose is

to show it a place which will give way if it pushes and so give it the room it wants, so the way to rub its tail against a bicycle tire is to expose it to heat. We fill the boiler of the railway engine with molecules of water, and they stop talking to one another and galop about in the form of steam, trying to get out, or, as we say, expand, so as to be the distance they like from one another.

You can make a sort of engine with an air balloon. Inside the balloon you have molecules of air uncomfortably crowded and therefore wanting to get out. Give them an exit and they will push out through it just as the steam molecules do in a steam-engine and until the balloon is exhausted this push will go on. You could arrange a railway engine on the same plan with men pumping up air into the boiler instead of a fire turning water into steam. The only reason why we do not do this is that the other way is better and easier. Why is it easier?

It is because instead of doing all the work ourselves *we are getting the sun to do most of the work for us.* That is so strange a truth that we must think about it in the next section.

XVIII. ANOTHER KIND OF HEAT

Think for a minute of the whole universe—earth, sun, stars, and the space between them. Everywhere there is matter; even in so-called empty space there is a little matter. And all this matter is dancing molecules dashing around, sometimes faster, sometimes slower. We can measure their speed with thermometers because what we call heat is the speed of molecules.

But there is another kind of heat called radiant heat. It is hard really to understand what this is like until we have read the last part of this book, but we can get a good enough picture of it this way. First of all let us see why men decided radiant heat must exist. The heat we have been talking about so far is very simple to understand; it is just dancing molecules. We know about it because our bodies are able to tell us about it, and the faster the molecules round us dance the hotter we feel. A cold thing can be made hot by fast molecules next door to it banging its own molecules and making them dance, too.

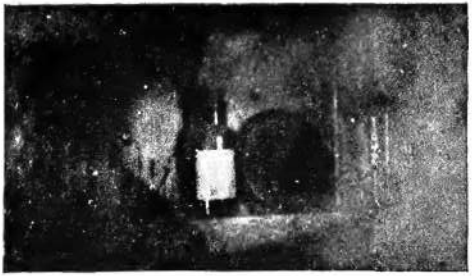
But now think of this. Have you ever been in a Pullman car some sunny day in winter when outside it has been all snow and ice? Have you ever sat in the sun as it shines through the sealed double window? If so you have felt very hot indeed, as hot as if you were in a desert at midsummer, and this has not been because of the steam heat; because, if you move out of the sun, though the steam heat may keep you warm enough, or even too warm, you do not feel as scorched as in the sun. Now, if when the train stops you have put your head outside, you will have found that, though the sun was shining, it was bitter cold. Now how can the sun make the molecules round you and in your skin dance so madly when the molecules in the air outside are dancing far less madly? This is the radiant heat of the sun which can pass through cold space and yet make you hot.

Radiant heat does not work by the molecules of the sun banging the molecules in the space between our air and the sun, and these molecules banging the air molecules and

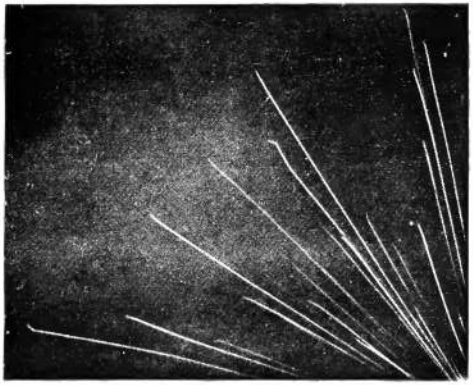
the air molecules banging the window-glass molecules and the window-glass molecules banging the Pullman air molecules, and these at last banging the molecules of your skin. It comes straight to you, in the way in which light does, and indeed it is a kind of light. That is all I can tell you about radiant heat now, but I am going to tell you a great deal more before we get to the end of this book. Only remember that there are two kinds of heat, radiant heat and the heat of banging molecules; both of them do the same to any molecules that come in their way, that is, make them dance faster, but radiant heat does not have to bang from molecule to molecule. It travels to distances as from the sun to your skin in another way about which you will hear later.

I am going to tell you just two things about radiant heat, so that you may remember the difference between it and the other kind of heat. I said it was like light. It really is a kind of light, only it is invisible to our eyes. It is not invisible, however, to a special kind of camera and you can actually take a photograph of a kettle boiling in a pitch-dark room. Here, indeed, is such a photograph taken in the dark. An electric stove was turned on so as to get hot, but not hot enough to give forth a glow, and the radiant heat was reflected onto these objects. There was absolutely no light in the room; the photograph was taken by the fire's radiant heat. (Plate I, No. 1.)

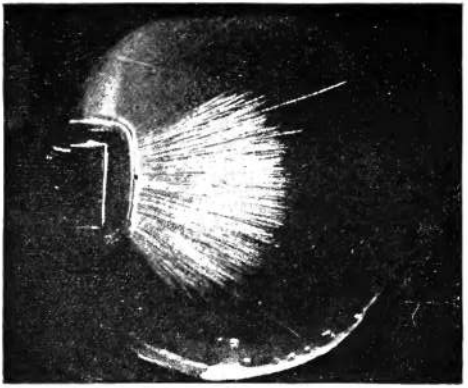
The other thing is this: turn to Fig. 18, which shows you a vacuum flask for holding liquid air. Inside the glass is a space between two walls. This is a vacuum out of which the air has been sucked, so that no molecules can be banged



1. A PHOTOGRAPH TAKEN IN COMPLETE DARKNESS BY THE HEAT OF A STOVE



2. TRACKS OF ALPHA PARTICLES



3. TRACKS OF ALPHA PARTICLES

PLATE I

by the hot molecules inside and so that these do not lose their heat by banging outwards to the outside world.

But if you broke open an old thermos flask you would see another thing inside it. The inside wall of a good thermos is coated with a kind of silvery paint. This is to stop the radiant heat from getting out. So the thermos flask stops heat from escaping in two ways—the molecular banging heat by a vacuum and the radiant heat by a special paint.

Now, having been introduced to radiant heat, we can see how a steam-engine is a way of getting the sun to do work for us.

For an enormous number of millions of years the sun has been pouring out heat in all directions through space, and some of it has bathed this planet on which we live. In course of time there began to be vegetation on the earth, and all plant life is a sort of machine for storing the heat from the sun. Plants use the sun's radiant heat to build up their bodies cell by cell, and when the plant dies there is in their wood and leaves and roots all this energy lying asleep.

For millions of years more and more plants lived and died and became buried beneath the ground. Gradually their bodies turned to stone—to coal, as we call that particular kind of stone. And then men came and dug up the stone because they found that by setting fire to it they could release the sun's energy lying useless in it.

The coal burned; the sleeping energy of the sun, which had left the sun millions of years before, began to work and produce heat; the heat was put to the water of the

engine; and the wheels turned and off you went to the Chicago World Fair at sixty miles an hour. Remember that the energy driving you there came from the sun millions of years ago, and that when you buy a railway ticket you are putting the sun to work.

XIX. WHAT THE MOLECULES DO TO MAKE WEATHER

Now let us look at something that is happening all the time, namely the weather. Let us try to see the weather in all its changes in terms of dancing molecules.

First go back to the glass of water with a layer of alcohol on top, in Fig. 7. We saw how the dancing molecules of the alcohol banged their way down in among the molecules of water, in spite of their being lighter than the water below them. Of course other molecules of alcohol were dancing upwards and mixing with the air above, though we could not see them. Now this mixing which goes on all over the world wherever any liquid is lying on the surface of the ground is one of the most important of the things that make life possible.

Leave a glass of water anywhere in the sun or in a hot room, and in a day or two quite a lot of it will have disappeared. We know that nothing can possibly cease to exist altogether, so that we know that the water which was in the glass must be somewhere else. Where has it gone? The molecules of water have danced their way up into the atmosphere. It has evaporated, as we say.

Evaporation is the grand dance of molecules which makes all life possible, and the weather is controlled by it. In-

stead of a glass of water think of the ocean with the sun shining on it. The radiant warmth of the sun is, of course, making the molecules of water in the ocean move faster, and more and more quit talking to their next-door neighbours and race off into the sky.

When this happens some of the molecules in the sea are too fat and heavy to follow. Remember that in among the molecules of water, that is the dancing trios of one atom of oxygen and two of hydrogen, are the molecules that make up the salt in the sea. Now these molecules of salt are far too heavy to follow the music of the sunlight and to dance off into the sky, and that is very fortunate for us, for it is the reason why the rain water we drink is fresh instead of salt.

What happens to the molecules of water which have danced off into the sky? They float about, mingling with the molecules of air. They are blown here and there by the wind. But what is the wind in terms of dancing molecules?

Remember that one rule all molecules of gas like to obey is the rule that all molecules in any one place must be dancing equally fast. If some molecules are dancing faster than others, very soon the two sets will have bumped into one another sufficiently often to slow down the fast ones and to speed up the slow ones.

Bearing this rule in mind, think of the sun shining down on the sea and the land by its side. The surface of the land gets hotter than the surface of the sea, because the sea is always turning over and mixing the cooler water underneath with the top layer. You can easily prove this for

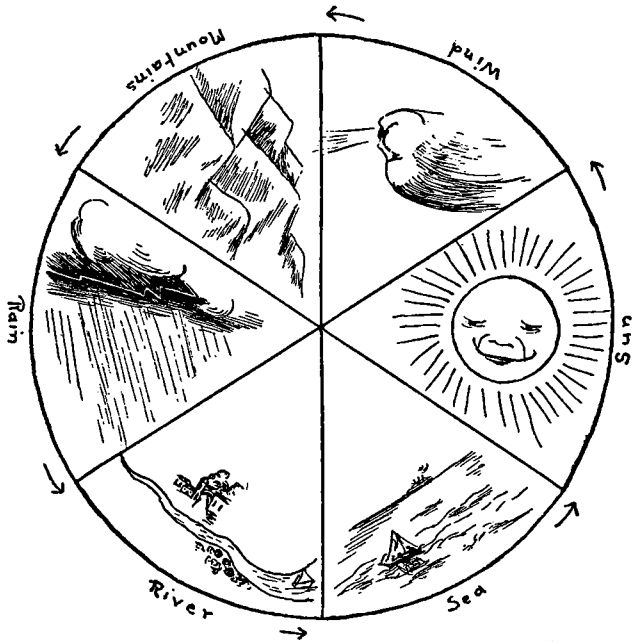
yourself; choose a nice hot day by the sea and lie down on the sand in your bathing-suit; you will soon want to get up, as the sand will be too hot, yet the sea will be nice and cool for swimming.

This being so, it is plain that the air-molecules above the sand are being banged by the sand molecules far more energetically than are the molecules of air over the sea by the water molecules. This makes the air over the land dance faster than the air over the sea and so the molecules over the land get farther apart from one another than those over the sea.

Now think of the air a mile high over the land and the air next door over the sea a mile high, too. They are like two columns standing up against one another, and one of the columns weighs much less than the other because there are fewer molecules of air in it, since each molecule is farther apart from the next. The heavier column over the sea pushes the lighter column over the land until it falls over on top of it, and that is the wind. Or put it in another way: all the air molecules want to be dancing at the same pace and to be an equal distance apart, so that those over the sea rush in among the ones over the land to make matters more equal.

You can produce exactly the same effect by putting some inky water at the bottom of a saucepan and some clean water at the top; then when you put the saucepan on the fire, and the molecules at the bottom begin to be banged about, you will see how they rise and mix with the slower-moving molecules above. That is the way the air is always

behaving. Colder air rushes in from the sea, hotter air mounts up to the skies, leaving more room for the cold air below. And that is the wind.



The eternally revolving wheel that makes the weather

20.

Now this wind from the sea is laden with the molecules of water in the form of vapour which have danced their way up from the surface of the sea. Only a certain number of these water molecules can be held up in the air, and

the exact number depends chiefly on the temperature of the air. The colder the air becomes the less moisture will it hold up. So the wind blows the moisture from the sea over the land high up in the sky, until sooner or later it reaches a place where the temperature is cooler. Perhaps a range of mountains or a cold wind from somewhere else meets the moisture-laden part, and at once the air is unable to hold as many of the water molecules. So it drops a great many of them, and that is what we call rain.

Rain, then, is water from the sea that has first danced its way up from the surface under the influence of the warming sun and then got tired of dancing, so to speak, and tried to huddle closer together in the sky, or condense into drops as we say, and tumbled down to earth again as a result (Fig. 20).

Sometimes the cold which the moisture-laden atmosphere meets is even greater and the water molecules have not time to huddle together in drops, but find themselves frozen into the crystal patterns called snow, and at other times the falling drops freeze into bits of ice and we have a hailstorm. But in any case the great cycle of moving molecules which we call the weather can be understood when we realise the laws which keep the molecules of air and water dancing in the sun's rays. Here is a picture which will help you to think out the weather in terms of molecules for yourself.

PART TWO

INSIDE THE ATOM

Did you know that . . .

the atoms of which you are made are mostly empty space?

if all the emptiness could be squeezed out of the atoms making up the world, what was left would be about the size of an orange.

one day a scientist quite by accident looked at his hand and saw his own skeleton underneath the flesh?

when there is thunder and lightning, exactly the same thing is happening in the sky as when you rub your fountain pen on your coat sleeve and bits of dust are attracted to it?

scientists use bullets thousands of times smaller than even the smallest of the atoms of which you have been reading?

scientists discovered an element in the sun long before anyone knew it existed on the earth?

there are stars made up of matter so heavy that it weighs forty thousand times as much as water?

we can tell that one star is $186{,}000 \times 60 \times 60 \times 24 \times 365 \times 160$ miles away? And yet we can weigh that star, tell of what it is made, how hot it is and whether it is moving away from us or towards us?

when you look at a certain bright star you can remember that the light coming into your eye from it left that star before your grandfather was born; and yet this is one of the nearer stars in the sky?

sooner or later our sun will collapse like a balloon and lose nearly all its light and heat?

This is the kind of thing that is explained in Part Two of this book.

PART TWO

INSIDE THE ATOM

I. SMALLER EVEN THAN AN ATOM

We have read about the dancing molecules and atoms, the smallest parts of anything, racing through space faster than anything we can see; banging into one another, moving faster to make us feel hot and slower to make us feel cold.

Perhaps you have pictured them to yourself as tiny hard elastic balls, bounding and rebounding. Perhaps you have imagined your body whacked and belaboured by countless trillions of them, like a swarm of flies on a hot day.

But now we are going to find out something even more surprising than these facts which have so far interested us about atoms. For we are to discover that they are not hard, unbreakable little balls at all. They are not even the smallest parts of matter!

Oh! but, you will say, what a fraud they are! We have been reading about atoms as uncuttable littlest bits of matter and now we are told that they are nothing of the sort. Let us think back for a moment. What is a molecule? Re-

member that when men first decided that they existed, no one had ever seen one; only the great detectives in the adventure of finding out how things are made came to the conclusion from certain clues they picked up, that there must be molecules.

Suppose you were in a dark room feeling around to find what was on a table. You might come across something round and smooth and cool. In the dark you could not see it, but you would decide from what you felt that the object was an apple and then when you tried to eat it you might find it was a rubber ball. That is just what happened with the molecules. Because of the way gases behaved when you heated or compressed or mixed them, the scientists decided that all could be explained if the gases were made up of molecules. Because of the way one thing mixed with another to make chemical compounds, they decided that all was easy to understand if the smallest part of every element was an atom, and they saw that sometimes a molecule consisted of two atoms just alike and sometimes of two or more atoms of different elements. They did not worry about what was inside the atom because that did not make any difference to what the atoms did to one another in their chemical experiments. They supposed they were hard, solid balls because that was the simplest thing to suppose.

But one day it happened that a great scientist saw something happening in his laboratory that made him and others think hard as to the inside of an atom.

As long ago as 1859 a man named Plücker took a glass tube and decided to find out what would happen if he

passed an electric current right through it. He fixed a piece of metal at each end and joined them up to wires fitted to an electric machine, just as you might fit a bell or an electric-light bulb. Nothing happened at all; but then he took the tube and pumped nearly all the air out of it. You know what that meant. He expelled a great many molecules of oxygen and nitrogen, and left the rest feeling uncomfortably lonely.

Now when he passed the electric current through this vacuum glass tube he saw something quite new. A green light seemed to be flickering about in it. What was this light? All sorts of people began to study it and to make guesses about it and especially a British scientist named Sir William Crookes. One thing was quite certain. If you put a piece of metal inside the tube in the path of the green light, a shadow was cast on the side away from the point at which the electric current entered the tube (see Fig. 21). So that it was clear that this mysterious thing came from that point which is called the cathode, and so they called the light cathode rays.

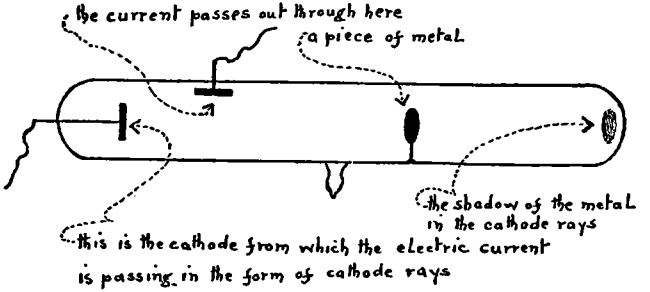
For years and years scientists studied the cathode rays; they watched what happened when magnets were brought near, when tiny amounts of other gasses were put in the tube, when the rays were made to run obstacle races of one sort and another, and at last an Englishman named Sir J. J. Thomson was able to announce that he knew what they were, that he had weighed them, measured their speed, and that all this information was about as surprising as anything that had ever been discovered.

For these rays were not rays at all, but tiny particles

of matter, tiny atoms, in fact, but that they were only one eighteen-hundredth part of the weight of any atom so far known. What were they and whence did they come?

They were little bits of matter shot off into the vacuum tube from the cathode directly an electric shock passed through. They were indeed nothing more nor less than bits of that mysterious thing, electricity, atoms of electricity,

An early type of vacuum tube

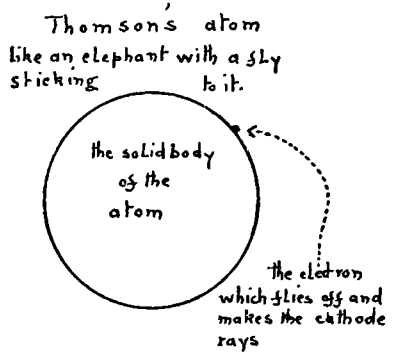

The current passes out through here
a piece of metal
the shadow of the metal in the cathode rays
this is the cathode from which the electric current is passing in the form of cathode rays

21

or electrons, as they very soon began to be called. Just as an atom was the smallest piece of any element, so these electrons were the smallest bits of electricity, and they were to be found inside all atoms of all elements! Indeed electricity was nothing but bits of the atoms themselves shot along from atom to atom.

When the tube was quite full of air these electrons banged into the molecules of air, which were at least one thousand eight hundred times their size, and usually a

great deal more; and so they very soon got stopped and the electric current would not pass. Imagine yourself running across a field crowded with elephants, without being able to turn aside if you saw one ahead; the chance of your ever getting across that field would be small. But if most of the elephants were led off you would be more and more likely to find a gap, even if you could not look where you were going, and to get through.



22.

So with the electrons. When the tube was nearly exhausted of these great lumbering monsters of molecules, they dashed through and the electric charge was not stopped.

One thing was certain from the start; since it made no difference at all of what material the cathode was made, it could not be a special substance that contained electrons. Everything, all atoms, had electrons inside them ready

to be shot out when an electric charge came through. The atom, instead of being a hard ball, unbreakable and the same all the way through, was evidently some kind of box packed with electrons, and that was something very different from anything Dalton had imagined.

But do not think that Dalton was "wrong"; remember that for his work it was quite good enough to think of the atom as hard, for nothing had been discovered to make it necessary to think the contrary. Right in science often means "as far as we know, not wrong."

It was only when Thomson discovered what cathode rays really were that Dalton's idea of an atom needed to be changed. Here (Fig. 22) is a picture of what Thomson imagined the atom to be. It is rather like an elephant with a fly sticking to it and the fly is the electron. We are going to see more about this later, but first we are going to look at another discovery which came from the cathode rays and seemed even more extraordinary than the electron.

II. HOW A MAN SAW HIS OWN SKELETON

In 1895, thirty-six years after Plücker watched the cathode rays, a German scientist named Röntgen was using a cathode tube to see if he could discover something, though he did not quite know what. In his own words, he was playing around with the vacuum tube, "looking for invisible rays." Everybody knew that the light you could see with your eyes was not the only kind of light. There was, for example, ultraviolet light, which human eyes could not see, but which was plainly visible to the eye of a camera. If you took a certain kind of chemical with the long name of

barium platino-cyanide, and painted it onto a piece of cardboard, it would glow, when these invisible rays shone on it. So Röntgen had painted a piece of cardboard in this way and put it handy on a table in his workroom.

Next he had taken a cathode tube and carefully covered it up with black paper, so as to keep any of the light from the cathode rays from shining out into the room. Then he thought he would turn on the current to make quite sure that there were no holes in the black paper through which visible light might come. Everything was as it should be; not a speck of light penetrated into the room. But what was that over there? The piece of cardboard on the table was glowing brightly!

"What did you think?" a friend asked, afterwards.

"I did not think," he replied; "I investigated."

"He seemed amused," this friend wrote later, "at my remonstrating with him about keeping *the* screen lying about in his laboratory. I told him it was a *historical screen* and should be preserved in a glass case. I hope he has carried out the suggestion. For the sudden shining of that screen undoubtedly led to one of the greatest discoveries of modern times."

What a wonderful museum could be made of all the important accidents that have given mankind knowledge. Let us look at some of the exhibits that could be put in such a Museum of Great Accidents.

We might begin with the bath in which a great thinker of the ancient world lay one day dawdling and dreaming instead of washing himself, until suddenly he noticed that, if his body slipped in, the water tried to get out, and so

discovered the important fact that a body displaces an equal bulk of water, which is the beginning of a great science. He was so excited that he rushed down the road as he was, crying out, "I've got it!" Or so the story goes! We might have in the museum the clothes he left in the bathroom in his excitement.

Next we would have the "glasses" through which a man named Galileo one day was looking at the skies, when quite by chance he turned them in the direction of the planet Jupiter. He noticed two little stars to the right of the big star and one to the left. Next day, as he says, "led by I know not what fate," he looked again and found that all three little stars were now on one side and closer together. It was the accident which led to mankind knowing that there were other planets like the earth with moons circling round them and it was therefore one of the greatest accidents in the history of the human race.

Perhaps we ought to have Sir Isaac Newton's apple in our museum, though apart from the fact that it must have become rotten long ago, if it was not actually eaten by the great scientist, some people deny that the story is anything more than a story. But if Newton was actually helped to discover the laws of gravitation by the accident of seeing an apple fall, then that apple was certainly the most important apple ever grown; even more important than William Tell's, and it would deserve a place in our Museum of Great Accidents.

We shall hear about one or two other such accidents later, but for the moment we must turn back to Röntgen's tube. There it lay wrapped up in black paper, and from it

was coming some mysterious invisible light able to push its way right through the black paper, as if it had been transparent glass, and to become visible when it fell on the cardboard coated with barium platino-cyanide.

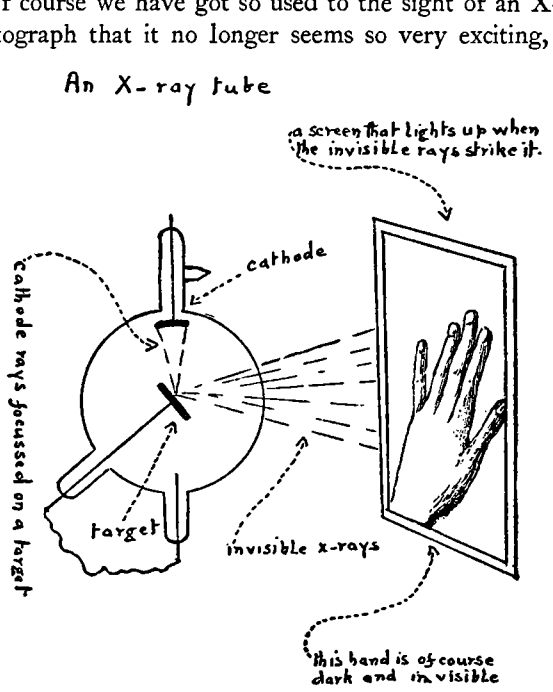
What on earth was this strange thing? Röntgen did not know, so he called it X-rays; just as when we do a problem in arithmetic in which you have to find out something unknown we say, "Let X be the unknown quantity." And this is the strange accidental way in which X-rays, about which everybody now has heard, came into the world of man's knowledge.

One thing soon became certain about X-rays, and that was they were produced by the cathode rays whenever these hit against something hard. Experimenters learned how to put little metal targets inside the vacuum tubes and in the way of the flow of the cathode rays and always when the cathode rays hit the targets X-rays were given off. Of course you could not see them; they were quite invisible; but if you put a screen with the right sort of chemical painted on it you could see that they were there because of the glowing screen.

Then Röntgen did something which must have been as thrilling as anything a man ever did (Fig. 23). Holding up the screen in one hand, so that it glowed in the invisible X-rays, he put his other hand between the screen and the tube. He looked through the screen and saw the shadow cast by his hand and, lo and behold! the bones inside his hand cast a deeper and darker shadow than the flesh around. Being made of denser stuff than the flesh, the bones stopped more of the X-rays from passing through; and so for the

first time in history a living man saw his own skeleton (Fig. 24).

Of course we have got so used to the sight of an X-ray photograph that it no longer seems so very exciting, but

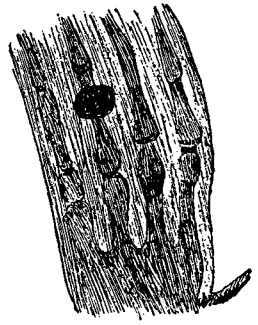

An X-ray tube
a screen that lights up when the invisible rays strike it.
cathode
cathode rays focussed on a target
target
invisible x-rays
this hand is of course dark and invisible

23.

it is not hard to imagine the amazement on that first day, when a simple search after "invisible rays" ended in a man's seeing his own living bones.

Röntgen immediately saw how valuable his discovery

was going to be to doctors and surgeons, and he sat down and wrote a description of it to a medical society; but he could not begin to guess some of the practical uses which have since been thought of for it.



Röntgen looked and saw his own skeleton — the first man in history to do it. Notice the ring on his hand.

24.

But apart from all their practical uses, X-rays have been a clue which has helped to unravel even greater mysteries about how we and the universe are made.

III. WHAT THE HAPPY ACCIDENT OF A PASSING CLOUD REVEALED

We have now seen two very strange things leading on to unknown mysteries—the cathode rays of high speed electrons far tinier than any atom, and the mysterious X-rays

penetrating through solid matter as easily as light through a glass window. Now we will look at another complete accident which afforded us another clue for our detective hunt.

This time it was a Frenchman who was playing around and who discovered something far different from anything he might have been expecting. His name was Henri Becquerel. It was 1896, one year after Röntgen had stumbled on X-rays. Becquerel was thinking of the piece of cardboard which glowed in Röntgen's workshop. Everybody knew of other examples of such a glowing light—phosphorescent foam on the sea, glow-worms and fireflies and several chemical paints; all had just this same sort of glow. Perhaps, thought Becquerel, all phosphorescent things can pass their rays through opaque objects, like the black paper Röntgen was using.

So he began experimenting with various chemicals. First he took a photographic plate and wrapped it carefully in black paper to prevent it being fogged by ordinary light. Then he took a special kind of chemical which becomes phosphorescent when put in sunlight. He held it for some time in the sun and then carefully wrapped it up against the black paper containing the photographic plate.

When he came to unfasten the parcel in a dark room and to develop the plate, sure enough it had become fogged. "Ahah!" said Becquerel to himself. "Just as I thought; the light from any phosphorescent object can push its way through opaque things like this black paper."

He decided to repeat the experiment, but just as he was about to expose the chemical to the sunlight in order

to make it phosphorescent a big cloud came over the sun and made the day too dark to do anything more. So M. Becquerel, being a very busy man, took his packet, the plate in the black paper and the chemical, and put them away in a dark drawer.

For some days he had other things to do, but one morning he happened to open the drawer and decided to tidy the things in it. What was he to do with the packet? He would develop it to show how the plate was unfogged, owing to the cloud having spoiled the experiment by preventing the chemical from becoming phosphorescent. He did develop it, and, much to his surprise, the plate was covered with fog, just as if the phosphorescent light had played on it.

Now once more an accident was going to help a man to make a great discovery. If only we could catch that cloud it would deserve a special space in our Museum of Great Accidents.

Why was the plate fogged? Not because of phosphorescent light passing through the paper. Then perhaps the first plate had not been fogged by the phosphorescent light, either. Becquerel began to tie up his plates with other kinds of chemicals. He prepared all sorts of phosphorescent substances and most of them had no effect on the hidden plate at all. Only when these substances contained a little of a very rare element called uranium did something push its way through the paper and fog the plate. And if there was uranium, it did not matter whether it was phosphorescent or not.

Now here was another very surprising mystery. What

on earth could there be about uranium that made it fog a plate put near it? Just as with Röntgen's X-rays, a kind of invisible light left the uranium atoms and could not be stopped even by thick black paper.

Things were beginning to happen to Dalton's hard, unbreakable ball of an atom; it was certainly very mysterious how something seemed to burst out from within it and perform such miracles as passing through flesh and black paper. Soon all over the world scientists were busy trying to track down the truth with the help of these clues. Two or three accidents which nobody was expecting had led to the threshold of a great surprise.

IV. MADAME CURIE DISCOVERS RADIUM

We now have several clues to a great mystery. Whatever the truth about the atom, it is quite certain that somehow or other there are inside it vastly smaller bits of matter, the electrons, which shoot out of the atom into the outside world when certain things happen.

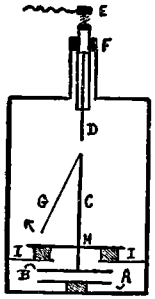
Further than this there is the matter of this element, uranium. Why does a photographic plate carefully wrapped up in black paper get fogged when uranium is put near it? Obviously some ray or other thing is shooting out of the uranium atoms and this thing is so small that it can slip between the molecules of the paper and get inside and act chemically on the photographic plate just as sunlight does.

It was along the lines of research suggested by this second question that the next detective went sleuthing. The next detective was a woman. Her name will be remembered

as long as science is interesting to human beings. It was Madame Curie.

Madame Curie and her husband set to work to see why uranium behaved in such a strange way, and to get a large supply of uranium they collected a heavy load of a kind of mineral found very often near tin mines, called pitchblende. Pitchblende was full of uranium, and like every other sub-

One of the cleverest detectives in the world: an electroscope



25.

stance containing uranium it shot something through black paper and darkened photographic plates.

Another thing it did was to collapse an electroscope. Now as the electroscope is one of the most amazing pieces of detective apparatus, it will be interesting to understand how it works. Here is a picture of an electroscope.

The outside lines are the glass walls of a special box. Inside there is at the bottom a little table, marked A. Above A is B, a metal plate fixed to C, a metal rod standing up-

right and kept in position by another rod, H, which rests on two little stands, I, made of something that will not let electricity pass through. That is to say that H and C are insulated, as we call it, just as a telegraph wire is insulated by the porcelain or glass insulators round which it is wound to keep it off the telegraph poles.

At the top of our box is a wire, D, which passes through a hole at F to the end of an electric current at E. That leaves just one other thing to mention, the hanging line marked G. This is a very thin piece of gold leaf, which is gold beaten down until it is much thinner than a sheet of paper.

Gold leaf, when it is charged with electricity, stands up stiffly with its lower unattached end high in the air. Now whatever this mysterious thing that is shot out of the uranium atom may be, it has the power to knock electric charges, that is to say, electrons, off anything brought near it. And so the detective puts the substance he is testing on the little table, A, and presses down the wire, D, until it touches C for a moment and thereby charges C and G with electricity. G now rises up in the direction of the little arrow. He can now tell whether the stuff on the table at A is shooting out the particles, because if so, the particles will gradually knock off the electric charge sticking to the gold leaf and G will slowly sink towards the ground.

In this way the very tiniest amount of the mysterious rays or particles can be detected and measured. If a piece of radium so small that you could not possibly see it were accidentally lost in a hospital, and thrown away with the

ash-cans, the electroscope would find it for you. The nearer you got to the lost radium the quicker would the gold leaf collapse.

When Madame Curie set to work on the pitchblende, she used a detector of the same sort as this electroscope, and she soon found that the pitchblende as a whole was shooting off more of the unknown thing than the uranium. That was the last thing she expected to find, for it meant that there must be some other unknown element far more powerful than uranium in its ability to shoot out parts of itself.

Happy accidents are not the only way in which the great scientific detectives have made their discoveries, and Madame Curie had to use unending patience in the work she set herself to do. All she knew was that when an electroscope was put near a piece of pitchblende the gold leaf collapsed towards the ground quicker than if it was uranium itself that was brought near, and therefore hidden in the pitchblende there must be an unknown element giving out something from within its atoms in far greater quantity than uranium did.

There could not be very much of it, because otherwise it would have been discovered long before. And so month after month Madame Curie patiently divided up tons of pitchblende into the elements of which it was composed. She got rid, one by one, of all the known elements until at last there remained a tiny pinch of something new. So little was there of this new thing that if you extracted all there was of it from a hundred and fifty tons of pitchblende you would be lucky to have an ounce of what you were looking for.

But when Madame Curie came to examine this little pinch, which she called radium, she found that it was the most surprising thing that had ever been discovered. For every atom of radium was forever shooting out from within its depths some form of energy and never seemed to get tired. That is to say, an atom of radium is like an engine that never needs fuel put into it and never stops working.

V. THE SCHOOLMASTER WHO HUNG UP HIS PUPILS AND ELECTRIFIED THEM

I have given you the story of some of the clues that were discovered in the search for information about the inside of the atom, but it would be impossible to tell the full story. We must now let Sherlock Holmes tell us where it all led to.

When Thomson actually weighed the electron and showed that it was nothing more nor less than a piece of electricity, he decided that whatever it was, the atom was obviously not a hard unbreakable ball. There you could see bits of it breaking off in the vacuum tube and forming the cathode rays. What, then, was the atom?

First of all we have to remember that there are two kinds of electricity. Let us go back two hundred and fifty years or so and be introduced to Stephen Gray, a schoolmaster in England. One day he was doing some simple experiments with a friend. He had read how, a hundred years before, a man named Gilbert had rubbed a piece of amber and that little bits of paper and other light objects were pulled towards the amber directly it was rubbed. Gray and his friend spent the day rubbing this, that and the other, and

they found that if you rubbed a long glass rod with a piece of cork on the end, or a fishing-rod fitted with an ivory ball, the cork and the ball both pulled the bits of paper towards them even when you rubbed the other end. So they rigged up a long wire, hanging it from the ceiling with bits of silk, and they found that when they attached a glass rod at one end and rubbed it, the same thing happened at the other end, even though the wire was hundreds of feet long.

Then the silk supports broke and they tried hanging their wire from the ceiling with other short wires, but now the experiment would not work at all. Of course we would say that what they had discovered was the conductivity of the pieces of wire and the non-conductivity of the silk.

Gray had to get back to school; so he left his friend to try electrifying "a hot poker, a live chicken, a large map, and an umbrella" while he hurried off to take his classes; but he could not get electricity out of his mind and almost before they knew it he had strung up several of his pupils from the ceiling by silk cords and was putting rubbed rods to their toes so as to see the little bits of paper attracted as by a magnet to their noses.

What Gray had been experimenting with was what we call positive electricity, which attracts things to the charged object. It was a Frenchman who discovered that in certain circumstances a charged object repelled or pushed away light balls of paper and such things, and this repelling electricity came to be called negative electricity.

Now Thomson showed that the electron was an "atom" or smallest possible part of this negative electricity, and

since any ordinary atom is charged with neither positive nor negative electricity he came to the conclusion that there must be two parts to the atom, one the negatively charged electron and the other a positively charged part to balance it. So he suggested that the lightest atom, that of the gas hydrogen, consisted of a round ball or "nucleus" charged with positive electricity and far bigger than a second ball, sticking to it rather like a fly on an elephant, the negatively charged electron. Then when a charge of electricity passed through the atom, the smaller bit shot off as in the vacuum tube. We have already seen a picture of Thomson's atom.

You will see that, just as in the case of Dalton's atom, Thomson's atom was supposed to be a certain shape because that shape explained something which had been observed about the unseen atom; and if we had never learned more about the atom than Thomson knew, we would be perfectly content with his picture of an atom to this day.

But the scientists found out several things that could not be explained by imagining the atom as an elephant of positive electricity with a fly of negative electricity sticking to it. Things were more complicated than that.

VI. HOW WE ARE MOSTLY MADE OF EMPTINESS

The reason why people had to give up imagining the atom to be as Thomson had suggested was that certain scientists invented a very remarkable kind of target practice.

Here was something shooting out of radium and other elements; why not use it as a bullet and bombard atoms and

see what happened? It is true that the target was far too small to be seen, but they could tell whether a hit or a miss had been scored, by the path of the bullet afterwards. If you hit two balls or marbles together, you can see if you hit or miss by the direction of your marble after the moment when the two should have met. So with the bombardment of the atoms.

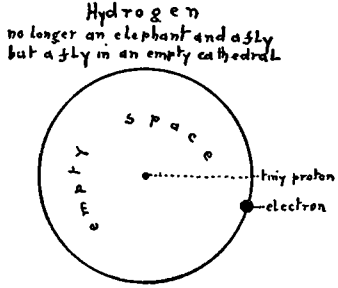
As millions and millions of bullets were being used, they could calculate exactly what shape the target must be, because on the average so many would hit and so many would miss, according to the size. If in every million five hit, then the target must be of such a shape and size; if fifty hit, another shape and size; and so forth.

They soon found, by counting the hits, that quite certainly the elephant-and-fly idea of the target must be wrong. From the path of the projectiles it could only be that the target, the atom, was pretty nearly all empty space and that the bullet passed right through. Further, it appeared that in the centre of a huge emptiness there lay a piece of matter far smaller even than the electron, which rushed round and round at a terrific pace in a ring on the outside of the atom.

Here was something very surprising indeed, and found out by means of a shooting expedition even more surprising. People tell us of the excitements of big-game hunting, but no tiger hunt could possibly be so exciting as this little-game hunt. To begin with, the bullet with which a man shoots a tiger is a slow-coach snail, compared with these bullets which went at least twenty thousand times as fast. So fast did they go, indeed, that one ounce of them would

have done as much damage as ten thousand tons of lead bullets. Was it surprising that they could go right through the target?

But now for another surprise—powerful as they were, they practically never scored a direct hit. The centre or nucleus of the atom, the proton of positive electricity, operated such powerful electric forces that it was almost always able to turn the bullet aside.


Hydrogen
no longer an elephant and a fly
but a fly in an empty cathedral
Space
Atom
tiny proton
electron
Instead of Thomson's solid atom with an electron sticking in it there is a tiny nucleus in the middle, then vast empty space, and an electron whirling round.

26.

It was the English scientist, Rutherford, that constructed a new model of an atom that satisfied all these facts and many more, and this is how he supposed the atom of the lightest element, hydrogen, to be (Fig. 26).

You see in the centre a speck, which stands for the proton, or positive charge of electricity. If this speck were drawn to scale you would not see it at all. It is many times smaller than the electron, which you see on the outside cir-

cle. And yet, although the proton is so much smaller than the electron, it weighs more than eighteen hundred times as much. In fact this inconceivably small proton is practically all there is to the atom; the rest is empty space with an inconceivably light electron dashing round on the edge.

It is hard to realise how strange this picture of the atom makes all our bodies and all the rest of the matter in the universe seem. You and I and all of us are nothing more than almost complete emptiness with minute electric charges dotted about at distances from one another, which, compared with their sizes, remind us of the distances between the sun and the farthest-off planets. Mr. Bertrand Russell once wrote that all matter, including your body and mine, is like "the Irishman's definition of a net, 'a number of holes tied together with pieces of string.' Only it would be necessary to imagine the string cut away until only the knots were left."

If all the atoms making up the earth could be squeezed together so that there was no empty space between the protons and the electrons, the size of the whole earth would be about the size of an orange. The rest of the earth's size is made up of mere empty space between the positive and negative charges of electricity.

VII. HOW TO RUB OFF AN ELECTRON OR TWO

Now let us go back to our delightful English schoolmaster who hung up his pupils to the ceiling, not to punish them, but to electrify them. You will remember that he used a

piece of amber or a rod of glass, and that, when he rubbed them, light objects like bits of paper or tiny pith balls were attracted to the rod as if by a magnet. What was he really doing?

Instead of thinking of the rod as a rod, try to imagine it as made up of countless atoms and molecules, and try to see these atoms as made like the hydrogen atom of which I gave you a picture. Only the atoms of which the rod is made are far more complicated than the hydrogen atom. Instead of having one electron racing round the central nucleus they have several. But however many electrons of negative electricity there may be—and we shall go back to this later—there are always in each atom enough positive charges in the nucleus to make the atom as a whole quite neutral.

If you take the rod, let us say your fountain pen, and rub it against your coat sleeve, you can see how the little pieces of fluff stick to it. Why? Because by rubbing you have knocked off some of the electrons from the atoms on the surface of the fountain pen, and these atoms have therefore got more positive electricity in their nuclei than they have negative electrons to balance it. The electrons which you thus knocked out of the fountain pen's atoms have become stuck to the atoms of the bits of fluff, which therefore have too many negative electrons to balance the positive charges in their nuclei.

Now, whenever an atom has lost one of its usual supply of electrons, it is unhappy, so to speak, until it has got another from somewhere or other; and whenever an atom has too many electrons, it does its best to get rid of them

as soon as possible. So that is why the bits of fluff stick to the fountain pen; the various atoms are exchanging electrons with one another so as to get back to normal again. And that is how what is called static electricity, the kind of electricity which comes from rubbing, is brought about.

Atoms can lose one or more electrons in a variety of ways, and when they lose them they are called ions. An ion is an atom which has lost an electron, which is therefore charged with positive electricity because part of the positive electricity in the nucleus is not balanced by the outside electrons.

VIII. WE START TO FIND OUT HOW HOT IT IS ON THE SUN

One of the most exciting things about scientific experiments is that very often what the scientist does in a small way in his laboratory turns out to be what Nature is doing on a large scale daily. Thus when you or I rub a fountain pen against our coat sleeve, we are doing exactly what Nature does every time there is a thunderstorm.

Remember we are making electricity by knocking electrons out of some atoms and fixing them on to others. Remember, too, that an electric current is nothing but the electrons rushing from one atom which has too many electrons to another which has too few.

Now in the sky, as we saw in Part I, molecules of water vapour have risen from the sea or damp land and are moving around in the form of a cloud. A rapid wind of air brushes past them, rubbing them as it goes. Just as with the sleeve and the pen, this rubbing knocks off electrons from the molecules of water vapour, which become, there-

fore, positively charged. The molecules of air at the same time become negatively charged by collecting these electrons. Sooner or later there is a flash of lightning, and that means that countless electrons have rushed back again to their proper homes. Of course I do not mean that each molecule gets back the identical electron it lost, but simply that every atom in the molecules of air and water vapour have their usual number of electrons once more and not too many or too few.

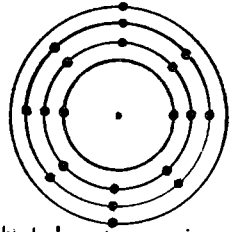
When next you see the hosts of heaven battling in the air above, as the ancients used to say, think that just the same thing is happening on a gigantic scale as you do when you rub your pen on your sleeve.

And that is not the only way in which electrons can be knocked off an atom. Another very common way is by making the atom sufficiently hot. Here, for example, is the picture of an atom of calcium (Fig. 27). You will see that it is much more complicated than the atom of hydrogen, for instead of just one electron rushing round the nucleus, calcium has no less than twenty. You will notice that they are drawn in four circles. In the inside circle there are two electrons; in the next two circles there are eight; and then in the outermost circle there are two again. We shall see later that all the atoms are made up like this, and that after the first circle they always seem to want to pack their electrons eight to the circle and never more. When a circle has its eight electrons, a new circle outside it is built up to lodge any more there may be. But we must have a look at calcium first.

Calcium is important for many reasons, but I will men-

tion only two. First calcium is the element that is absolutely necessary for the building up of good bones and teeth. We now know that the best way for us to have good teeth is to be sure that our mothers ate plenty of calcium-containing food before we were born! Second, calcium is important because it helps us to tell how hot it is on the surface

Calcium



Twenty electrons in four rings or petticoats, and, in the centre of a vast open space, the nucleus. When it is very hot calcium throws off these petticoat (see p. 85)

27

of the sun. It is easy enough to tell how hot the sun is on our own sun-porch, but how on earth are we to know how hot it is ninety millions and more miles away from us?

Now imagine the rings of electrons as petticoats round the nucleus. Hydrogen prefers to go about very lightly clad, but poor calcium has four thicknesses of petticoats. Is it surprising that when it is very hot calcium kicks off some of these petticoats? Now using this fact about calcium, it is

possible to guess how hot it is on the surface of the sun by simply seeing how much clothing the atoms of calcium are wearing there.

IX. HOW SODIUM WAS FOUND TO EXIST IN THE SUN

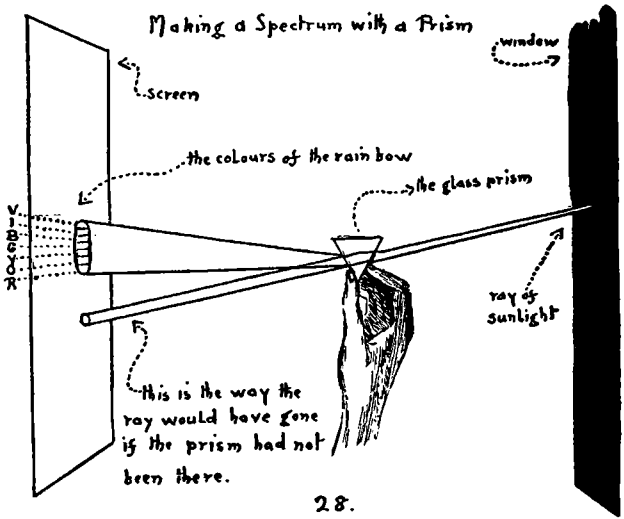
Now how can certain things we find out about atoms in laboratories help us to know not only what atoms there are on the sun, but how they are behaving and feeling?

When you realise that an electron is only an eighteen-hundredth part of an atom in weight, and that an atom is so small that 27 followed by eighteen noughts get into a box the size of the one in Fig. 6, it seems hard to believe that we can tell how many electrons the atoms on the sun have. Yet that is exactly what can be done.

Let us begin at the beginning. Everybody has seen a rainbow and most people know that a rainbow can be made by making a ray of sun go through a specially shaped piece of glass called a prism. If you can get hold of a prism it will be interesting to do the experiment shown in the picture, Fig. 28.

Let a ray of sunlight come into a darkened room through a hole in a thick blind and have a white sheet hung so that the ray hits it. Then take the prism and hold it so that the light passes right through it, and you will see that the ray gets bent as it passes through and that on the screen there appears not a simple spot of sunlight, but a band of colours like a rainbow. At the top you will see violet light, next indigo, then blue, green, yellow, orange, red in turn. Later we shall see that there is also invisible light

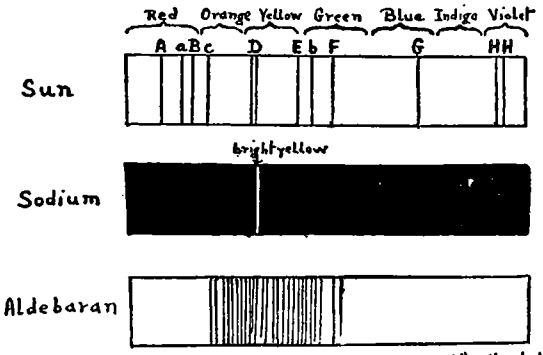
higher than the violet and lower than the red, but the adventure of invisible light belongs to the third part of this book, although we mentioned it a little while back when we spoke of Röntgen. In the picture, we have put the ray of light as it would have been had the prism not bent it, and, as well, the ray after it has been bent.



28.

People had been familiar with this spectrum, as it is called, for a very long time, but about one hundred and twenty years ago a young German, who worked in an optician's shop in Munich, noticed something new about it. He made rainbows with a prism and admired the colours passing from one to another and all the way from violet to red, but he also noticed that here and there were bands

across the colours that looked dark. It was as if at these places there was no light at all. These dark lines, although their discoverer never knew it, were to be the clue to more revelations about the sun and the stars than any other single discovery. They are called the Fraunhofer Lines, after the optician's apprentice, who saw them, and here (Fig. 29) is a picture of them. You must imagine that the top band



The spectra from three kinds of light with the tell tale finger prints which helped the detective scientists to know of what the sun and stars are made 29

is like a rainbow and you will see above it the colours marked so that you can tell in what part of the spectrum each line lies. Thus in the blue part there is a line that Fraunhofer labelled G, and in the yellow part another that he called D.

When Fraunhofer looked at the spectrum coming from moonlight there were all these lines in exactly the same position, and, also, when the spectrum of Venus was ex-

amined, there they were. This was not surprising, since moonlight and Venus light are just sunlight reflected off the moon and Venus.

But then Fraunhofer looked at the spectrum from the light of the star which the Arabs called the eye of the bull, Aldebaran. You can see this star burning bright and red near Orion's belt and the Pleiades. So far he thought that somehow or other these lines were due to the atmosphere cutting off some of the sunlight and so he expected the spectrum from Aldebaran to have the same lines. But it had nothing of the sort, for the lines from Aldebaran's spectrum looked like those in the lowest band in our picture.

Now whatever these lines may be, thought Fraunhofer, one thing seems certain, and that is that sunlight and starlight are different, and so probably the sun is made up of different material from the star.

That does not lead us very far on our way, you are probably saying; but now there comes another discovery which leads us much farther. Sir John Herschel tried what would happen if you burned a pinch of table salt in a flame and looked at the spectrum that came from the light. If you care to do so you can burn some salt and you will find that the flame becomes bright yellow. If now you were to pass this light through a prism you would find that instead of spreading out into a rainbow of colours, all the light appears as a bright line, brilliant yellow in colour, at exactly the spot where Faunhofer's D line comes in the sun's spectrum.

Now common salt is made up of two elements one of which is called sodium, and when another scientist called

Kirchhoff heated sodium till it became a glowing vapour, he found that it always gave out a spectrum in the form of this bright yellow line at the position D on our picture of the sun spectrum.

Next Kirchhoff did a very clever thing. He resolved to see what would happen if he made the sun spectrum and the sodium spectrum appear right on top of one another in the same space. So he made sodium vapour and then passed a ray of sunlight through it and let both lights pass down his spectroscope (or instrument for seeing a spectrum). There on the screen was the coloured spectrum of sunlight, but at the point where line D lay, there was an even darker band than ever. What could this mean?

It means that, whenever a ray of sunlight passes through sodium vapour, that vapour cuts off the light at the line D, and that every ray of sunlight must at some time or other pass through sodium, since line D is always there. Now there is no sodium in the earth's atmosphere, and so the only place for the sodium to be is on the face of the sun itself.

And so here is a way of knowing what the sun, millions of miles away, is made of, just as surely as if you could stoop down and pick up a piece of it to analyse in your laboratory.

Scientists soon found that every element had its own particular dark lines and that wherever you found these lines you could be certain that that particular element existed. In this way it was found that all sorts of elements, like hydrogen and oxygen, carbon and iron, copper and silver, all had lines in their spectra that corresponded to lines in

the sun's spectrum; and that means that these substances are to be found in the sun itself. Thus through Fraunhofer's Lines, we are actually able to know that the sun is made of the same elements as our own earth.

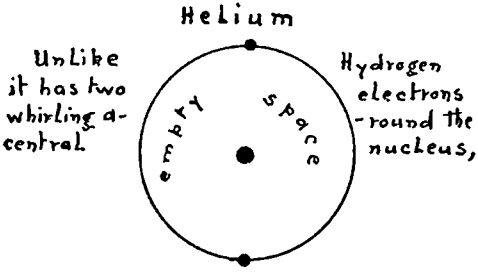
X. HOW HELIUM WAS FOUND ON THE SUN BEFORE IT WAS KNOWN ON THE EARTH

The next chapter in our story takes place in 1868. By that time Fraunhofer's simple apparatus for measuring and observing the spectrum had been much improved. All sorts of elements had been tested and their bright lines had been compared with the dark lines on the sun's spectrum, and nearly all the lines had been paired off satisfactorily. It had been found that there were many more than one line corresponding to each element; thus instead of the one bright yellow line which had first given sodium's presence away there were seen to be a double pair in the yellow part, and both of them, as well as many other lines, belonged to sodium.

But near these sodium lines was another, a thin one, which puzzled a British scientist named Lockyer very much indeed. He took all the charts of the spectra of all the elements and compared them one after the other with this part of the sun's spectrum, but in none of them was there a line to fit this thin one.

What could this mean? If you found that the sodium line or the hydrogen line or the lines of any other element known on earth were to be seen in the sun's spectrum, then you concluded that there must be that element ninety odd million miles away in the sun. But if you found a

line in the sun's spectrum which you did not find anywhere on earth, it must mean that it belonged to an element found on the sun, but not found on the earth. That is what Lockyer decided; that his new line, always to be seen in the same place in the sun's spectrum, must be made by a new element discovered on the sun before it had ever been detected on the earth.

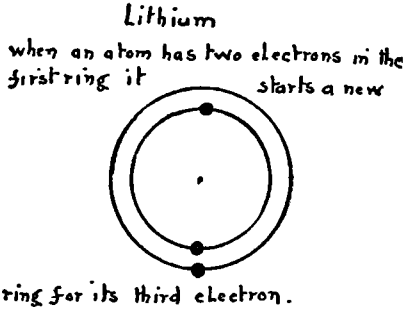

Helium
Unlike it has two whirling a- central
Hydrogen electrons - round the nucleus,
and as this is the number an atom wants it is so self-satisfied it never mingles with other elements.
(See p. 93)

30

Just think of the excitement of such a piece of detective work: to be able to discover a new kind of atom right across empty space; to be able to say that over there on the sun was something which nobody had ever seen here on earth. Lockyer very naturally called the new element, "the sun element," or helium.

Twenty-seven years passed. One day another British scientist was experimenting with a piece of mineral that came

from Norway. He was trying to find out all the different elements mixed up in it. He used all the usual chemical ways for testing it, and among other things he found that a gas was driven off. When this gas was examined under a spectroscope, behold—its spectrum showed the very line that had been found by Lockyer in the sun's spectrum. Here was helium discovered at man's feet a quarter of a century

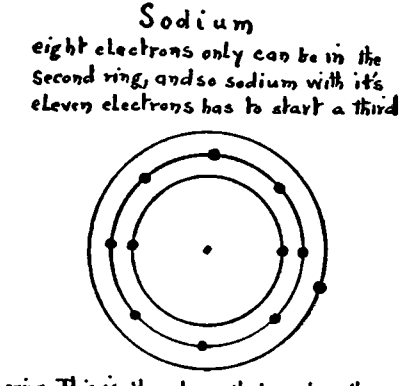


31

after man had first discovered it far away over his head in the sky!

Now why had helium managed to keep hidden all this time? Here is a picture of the helium atom (Fig. 30). You will see that round the tiny nucleus there fly two electrons in the same ring. That is, helium has one electron more than hydrogen. Now the element that has one more electron than helium is called lithium, and here is a picture of lithium (Fig. 31). You will see that the third electron is not flying round in the same ring as the other two, but in

a larger one outside. The next seven atoms each have one more electron than the last, until neon, the tenth element, has ten electrons circling round the nucleus in two rings, the inside ring with two and the outside ring with eight electrons. Now look at the eleventh element, sodium, about


Sodium
eight electrons only can be in the
second ring, and so sodium with it's
eleven electrons has to start a third
ring. This is the atom that makes the
yellow line, and was the first to be
detected on the sun.

32.

whose spectrum you have been reading. (Fig. 32). Sodium has one more electron than neon, but it is not in the same ring as the previous eight. The eleventh and last electron of sodium has started a third and new ring.

We can put all this quite simply by saying that only a certain number of electrons are able to move in one ring, and if there are more, then they have to begin a new ring. In the first, or smallest, ring there can be one or two electrons, but never more; in the other rings there may be any

number up to eight, but when eight have been put in any ring a new ring outside the full one must be begun.

Now you may be saying this is all very well, or all very dull, but what has it to do with helium not being found on the earth until long after it was found on the sun? It really has quite a lot to do with that, however. It seems that the elements prefer to have their rings full up with the complete quota of electrons; that is, they are more at ease if there are a full set in the outside ring. Hydrogen, for example, has one electron in the ring round its nucleus, and if we can put it that way hydrogen would much prefer to have two. But if hydrogen gets another wandering electron or steals one from another atom, it will at once lose it because, as we have seen, it will have one negative charge of electricity too much to balance the positive charge in the nucleus, and this negative charge will run off at the first opportunity. So what does hydrogen do to get a feeling of greater completeness?

It shares an electron with an atom of some other element. It gets so close to the other element that both of them can use each other's electrons to fill up the blank spaces, and the result is what we call a chemical compound. Hydrogen and oxygen, for example, combine, as we have seen, to make water. Two atoms of hydrogen, each having one electron in a ring which is really allowed to have two, and one atom of oxygen which has six electrons in its outer ring where eight is a full number, unite in such a way that all three share one another's electrons and feel all the better for doing it. I do not pretend that it is easy to see how this happens, but that it does happen seems certain,

for this very good reason: the atoms that have incomplete quotas in their outer rings are always combining with other atoms to form compounds, but the atoms with complete outer rings, like helium and neon, are perfectly content with life as they find it and do not combine.

And now you can probably see why it was possible for helium to escape being found out for so long. Helium with its two electrons *kept to itself*, and so chemists never ran across it in any of the compounds they examined in the laboratory. Until somebody stumbled on it in a pure state, it eluded everybody and even then it could not have been hauled out of hiding without the spectroscope.

XI. HOW ELECTRONS JUMP FROM ONE ORBIT TO ANOTHER

So far we have seen that it is possible to discover what elements exist on the sun and the stars by spectroscopy, or the science of looking at the spectrum; but so far nobody knows what these mysterious Fraunhofer Lines may be. They are rather like fingerprints for a detective who does not know that criminals have fingers. How do the atoms of all the elements leave these Fraunhofer fingerprints behind?

Remember, too, that Fraunhofer and Kirchhoff and the other early detectives knew nothing like so much about the atom as we have learned so far in this book. They did not know that it was mostly empty, with electrons flying round a minute nucleus. And so they had not the evidence to lead them to understand the fingerprints.

It was not until this century that the truth was discovered. A great scientist named Bohr showed that the elec-

trons are flying round in their rings or orbits at a terrific speed and that every now and then an electron leaves one orbit and takes up another, and that the Fraunhofer lines are the fingerprints left by an electron whenever this happens.

Look for a minute at any of these simple pictures of atoms that we have already discussed.

In the centre is a tiny nucleus. Remember that this nucleus, in the case of hydrogen at least, is far smaller than an electron, and yet it contains very nearly all the mass of the atom. Compared with the nucleus, the electron is very bulky and at the same time very light.

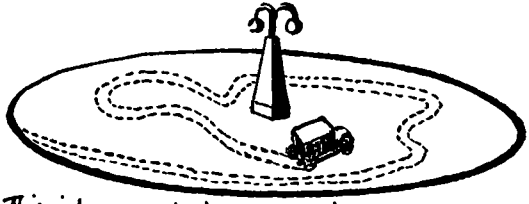
Round the nucleus is a region of emptiness so big compared with the nucleus that you can think of it as being like one speck of dust in the middle of a very large empty hall.

Flying round in circles are any number of electrons from one to ninety-two. You will remember that these electrons obey certain rules, as to the number that can share in any particular ring; two in the first, then eight in all the others, but never more.

Now here is the exciting thing: electrons do not stop in the same orbit always; every now and then an electron will jump from one orbit to another. When they do this they have to do it in a very remarkable way.

Here are two little sketches (Figs. 33 and 34) of a big open circle in the middle of a city. There is a statue in the middle, and in the first sketch you see yourself in an automobile going round the statue. The dotted line is the course

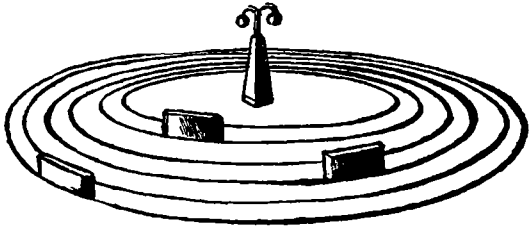
you take, and you see that you zigzag about as you please; provided there is no other traffic, you can go anywhere you



This is how an electron may not move - just anywhere round the central nucleus.

33

This is how electrons move, in special tracks like street cars. But unlike street cars they can jump



from one track to another without ever being in the space between! (see p 97)

34

like; you can go round in a wide circle and then head inwards and continue in any kind of orbit.

In the second picture there are several street cars going round, and of course they have to stick to their lines. There are three sets of tracks and on these the street cars go; they cannot, as you in your automobile could, go round in any circle they please. That is obvious.

Well, the electron is like the street car, it can only go in certain orbits and no others; but it can do a thing that a street car cannot; it can jump suddenly inwards or outwards and without going through the space between from one track to the next. Nobody can imagine how it can do this, but there is no doubt whatever that an electron that has been going round and round in one orbit suddenly and as if by magic is found in the next.

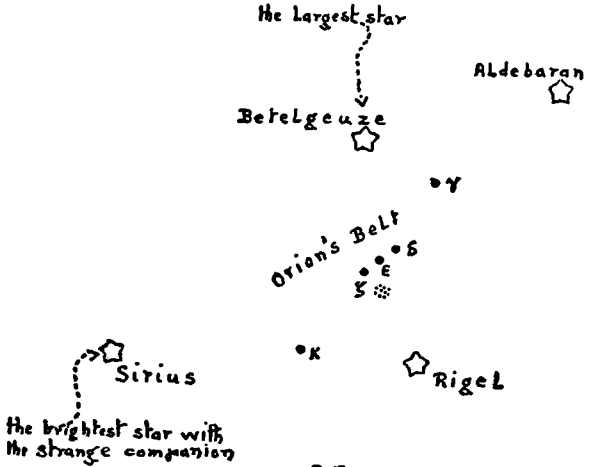
And now for the answer to the question that has been in the back of our minds for some time. Those fingerprints, the Fraunhofer Lines, on the spectrum are made whenever one electron jumps from one orbit to another. Every time this happens something is given out by the atom and signals its departure to our eyes by leaving a line when it goes.

And now when we think of calcium and its habit of shedding some of its petticoats of electron rings whenever things get too hot for it, we begin to see how it is possible for clever scientists to find out how hot it is on the sun or any distant star.

Clearly, if the calcium atoms have lost a certain number of electrons, those electrons will not be there to make the sudden jumps that they would otherwise be making. And so if we look at the sun's spectrum and notice that some of the lines are missing, we know at once that they are missing because so many electrons are missing. And as calcium

always sheds the same number of electrons at the same temperature, we can work out the exact temperature of any star, or of the sun, from the lines on the spectrum.

Using this method, what do we find? I think that what I am going to tell you now is one of the most thrilling things in all science, and in order that you shall enjoy



35

it to the full, I want you to stand on a clear winter night and pick out certain stars which I think you will know already. Here (Fig. 35) is a rough map of the part of the sky round Orion. Near the top right-hand corner you see Aldebaran, which we read about some time back. Farther above it and off our map you can see shining that little group that the ancients found so interesting. The Pleiades, they called it, and they believed that they were

six sisters and that there had been a seventh, the lost Pleiad who had fallen from the skies. Actually you will probably count at least eight on a clear night, and there are hundreds to be seen through a telescope.

Below and to the left of Aldebaran lies the constellation of Orion. The three rather bright stars, at equal distances on a slant, are his belt, and above them to the left is a brighter star still. This is Betelgeux, one of the two stars that I want you to look at when you have read what follows.

The other star that we are going to discuss is Sirius, the Dogstar, that flashing brilliant star lower down on the horizon farther to the left. It is by far the brightest star in the sky.

We are going to ask the question, What are the atoms like on our sun, on Betelgeux, and on Sirius? To find out we have to train a spectroscope on them and observe the Fraunhofer Lines.

We know all sorts of things about Betelgeux and some of them are so interesting that we may spend a moment on them, although they have nothing to do with our immediate subject. First we know how far away it is. Light travels 186,000 miles in a second and Betelgeux is so far away that it takes light 160 years to get to us from its surface. If you want to know the exact number of miles, work out this sum—Betelgeux is $186{,}000 \times 60 \times 60 \times 24 \times 365 \times 160$ miles away from us.

Then we know the size of Betelgeux. Its diameter is more than a hundred times that of our sun. It is the second largest star in the universe so far as we know. Lay a hundred Lincoln pennies side by side; then, if one penny is

the diameter of the sun, all of them will be the diameter of Betelgeux. Such a star is called a Giant Red Star, from its colour.

Now in a star like this the spectrum tells us that all the atoms have stripped off a good many petticoats. In fact, no atom has more than three left. This does not worry the lightest-clad atoms like hydrogen, but our friend calcium has shed one petticoat with two electrons in it, and all the heavier elements ending with uranium have shed several more.

But although as compared with atoms on the earth these atoms on Betelgeux are fairly lightly clad, this is nothing to the state of clotheslessness found in other stars. So now let us have a look at Sirius.

XII. A STAR FIFTY THOUSAND TIMES HEAVIER THAN WATER

Sirius is, as we have said, the brightest star in the sky, but it is by no means the biggest. It is quite a near neighbour, for light which takes 160 years to get to us from Betelgeux, takes only six and a half from Sirius. When you look at them both, remember that the light you see from Sirius, if you are twelve years old, started before you were six, but that from Betelgeux started before your great-grandfather was born.

Throughout the ages Sirius has been studied and watched by shepherds and astrologers, by weather prophets and fortune-tellers, simply because it is so conspicuous in the night skies. But nothing that people thought in the days of superstition could be half so surprising as the truth.

To begin with, Sirius is not one star, but two. That in itself is not so surprising, for there are thousands of stars which through telescopes turn out to be not one star, but two, revolving round one another just as the sun has the earth revolving round it.

But directly people began to try and calculate the sizes of the two stars difficulties turned up. They rubbed their eyes and went over the figures time and again for the figures seemed to say something about the couple which was absurd.

You know that if two bodies like the earth and the sun are considered, it is possible to find out all sorts of things about them by measuring their distances from one another, how fast the earth moves and so on. Thus if we know the speed of the earth round the sun and the size of its orbit and its weight, we can weigh the sun.

The same with Sirius and its companion star; astronomers watched their movements, measured their distances, and calculated how big the companion star should be in order that it should affect Sirius as it did. Try as they would, they found that if the companion star was made up of matter weighing the usual sort of weight, its diameter ought to be so big that it would fill up all the space between the two and instead of going round Sirius it would swallow Sirius completely and Sirius would be somewhere inside!

This was, of course, absurd, and so some other explanation had to be found. As the companion of Sirius was so small and yet influenced Sirius so violently, it could only be that the stuff of which it was made was enormously heavier than any matter known on earth. Indeed, calculations

showed that a piece of this star would weigh fifty thousand times as much as a piece of water the same size on earth. The dwarf companion of Sirius, therefore, was made up of matter far denser than man had ever imagined possible. Why was this?

The answer is that things have become so hot on that particular star that all the petticoats are off and there is nothing left of the atom but the bare nucleus, and so the atoms can crowd together far closer than on earth, or on Betelgeux, even. All the empty spaces between the electrons and the nuclei have been done away with, and the result is a dwarf star, heavier than any ordinary star, because it is not made up mostly of emptiness, as are the atoms of our own bodies, or of the earth or of most stars.

Now try to imagine what must have happened to a star like the dwarf companion of Sirius. Through the ages it has been getting gradually hotter and hotter. First one petticoat and then another has come off. Then comes the time when the heat is so great that the last petticoat, the ring with two electrons, goes. Remember that atoms always act with complete regularity; at such and such a temperature off goes such and such a petticoat. So, when the moment arrives, untold numbers of atoms instantaneously become stripped to the bare nucleus and the star as a whole suddenly shinks from a large star to a dwarf, not through vast ages gradually, but like a flash of lightning. Astronomers believe that when the right time comes, that is when the heat reaches the right temperature to strip off the last ring of atoms, a star becomes a dwarf overnight, losing nearly all its bulk, and its light and heat in the process.

In between Betelgeux, on the one hand, the sprawling vast vapoury giant, and the dwarf companion of Sirius on the other, lie most of the stars, including our sun. And here is something that may surprise and even frighten you. It can be shown that our sun is approaching the moment when its atoms will strip off their last rings of electrons. When that happens the sun will suddenly collapse like a punctured balloon into a dwarf, losing most of its light and heat in the process.

Of course that will mean the end of this world. But we must not be too worried about that, for when we ask an astronomer what he means by saying that the sun is approaching the moment when it must become a dwarf, we find that he means that this will happen in the next 2,000,000,000,000 years, which, says he, is a very short time from his point of view, but which, say I, is long enough for me not to worry about it too much.

XIII. BUT ATOMS ARE REALLY EVEN MORE COMPLICATED

We have seen what astonishing detective exploits can be carried out by studying the behaviour of atoms. We have also seen why things actually seen in the laboratories convinced scientists that the atom must be mostly empty space. Now we must take a little closer look at the way in which the atom is built up.

Look at any one of our pictures of atoms. We have shown the electrons going round the nucleus in rings and we have seen how in the first ring there can only be one or two electrons, and then in the next rings there can be any number

up to eight, but not more than eight. In the heavier atoms the outer rings can have as many as eighteen electrons, but we need not bother about that now.

This picture is really much too simple. To begin with, no two electrons can be in the same path. There are not eight electrons in one path in the second ring of calcium, for example; that ring is not really one track, but a bunch of eight separate tracks, each with a solitary electron whirling round in it. It would be impossible to draw all the tracks separately, but we must remember that every ring in an atom picture stands for a set of tracks and that no two electrons are ever found in the same track.

And so far we have thought of the nucleus as a tiny dot in the middle of the atom, but it is really far more complicated than that. The nucleus is made up of several separate parts, except with the hydrogen nucleus. Look back to the picture of the hydrogen atom. It has just one electron, or charge of negative electricity rushing round the nucleus, and to balance this the nucleus is just one charge of positive electricity and nothing else.

We call this charge of positive electricity a proton, so that a hydrogen atom is made up of one proton in the middle and one electron on its edge. When the hydrogen atom is comfortably undisturbed, as it is on this earth, the electron goes round in a path which is about twenty five million times as wide as the width of the proton in the middle. That gives you some idea of the terrific emptiness of the atom. But when the hydrogen atom is excited by the great heat of a star or by any of the other forces that excite atoms, the electron will jump from this near-by orbit to another

farther out. These jumps can only be of a certain size; the electron can only jump as if it was one of the street cars in Fig. 34, jumping from one track to another. It cannot just steer itself in any path it likes as the automobile driver does. And as we have seen if the atom gets too excited the electron will jump away altogether.

Now look at the atom of helium. You might suppose that as helium has two electrons round the nucleus the nucleus is made up of two protons to balance it. But that is not so; for to begin with, if that were true the atom of helium would be about twice as heavy as the atom of hydrogen and as a matter of fact it is four times as heavy. Remember that as far as weight is concerned the electron is so light that it hardly counts. Practically all the weight of an atom is to be found in the protons. If helium is four times as heavy, then it must have four protons in the nucleus. But then it would have four charges of positive to only two charges of negative electricity. So we come to the conclusion that there are inside the nucleus of an atom of helium four protons and two electrons, and then the electric charge would be just two, and that is balanced by the two other electrons on the edge.

You can see how complicated the nucleus of the heaviest elements must be. Actually the heaviest element of all, our old friend uranium, is made up of a nucleus with 238 positive protons and 146 negative electrons all bound together, and then in rings round this, each one circling in a separate orbit, there are ninety-two more electrons.

Just think for a moment how strange this is. We began by thinking of all matter as made up of tiny, hard, un-

cuttable balls, so small that no one could ever see them; but by careful study it has been shown that these balls are really complicated beyond dreams. This is a wonderful result, but surely what is still more wonderful is the story of how all this was found out. We have learned only about some of the simplest parts of the story, but I hope they will have proved interesting enough to make you want to go to the bigger and harder books which will tell you more.

We must now turn our attention to another question. You will remember that we said that whenever an electron jumps from one orbit to another nearer the nucleus it gives out something, which is sometimes detected by the Fraunhofer Lines and sometimes by other kinds of fingerprints. What is this something?

Look at that wall over there in the sunlight. You would say that the bricks and cement were made of dead matter. Do you know how it comes about that you see it at all? It is because that wall, like everything else in the universe, is made of dancing atoms, each one of which is partly made up of electrons moving incredibly fast. These electrons, acted on by what we call light, are constantly jumping from one orbit to another. It is these jumping electrons that enable us to see the wall. If all the electrons stopped jumping the wall would go out like a light turned off suddenly and we should see as little as if we had no eyes at all.

We must now see how an electron jumps and why.

PART THREE

WAVES

Do you know . . .

that the water in a sea wave does not move in towards the shore?

exactly what happens when a drop splashes?

that sound is caused by a splash in the air which makes waves, just as a splash in a coffee cup makes little waves in the coffee?

why a stick looks bent in water?

why your reflection seems to come from a place behind the looking-glass?

what happens when you hit a note on the piano to the molecules of air around?

that light is a wave coming into your eye and breaking on the atoms at the back of your eyeball?

that when a girl puts on lipstick she is making the waves from her lip to your eye longer?

that wireless waves, X-rays, and light are all exactly the same except that some are shorter than others?

that some kinds of atoms shoot out bullets forever without needing to be loaded by men?

that it is possible to see the bullets thousands of times smaller than atoms actually hitting targets which are atoms?

that you can photograph the tracks of atoms and electrons, although they are so minute that no eye could see them with the most powerful microscope?

This is the sort of thing explained in Part III of this book.

PART THREE

WAVES

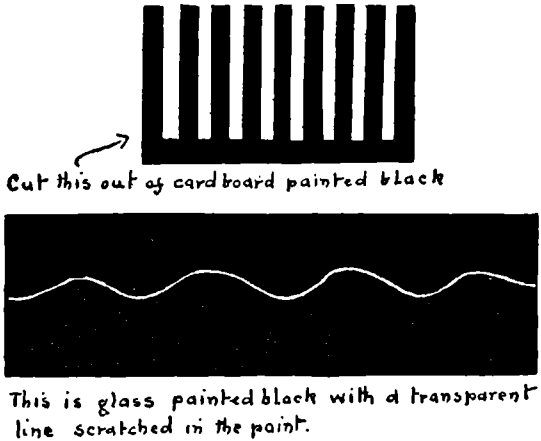
I. HOW DOES A SEA WAVE MOVE?

At the end of the last part we said: "We must now see how an electron jumps"; but as so often, in good detective stories, we have to start our hunt far away from what we might expect would be the best starting point. We are going to imagine that we are sitting down by the side of the sea, watching the waves breaking at our feet. You must have done this often, and so you will not find it hard to imagine it. But if you have never seen the sea, you can sit down by a lake or good-sized pond just as well.

Do you see that wave out at sea there, the big one with a white crest? Let us follow it as it rolls in towards the shore. We can see the water coming towards us, can we not? No, we cannot! For, strange as it may sound, the water is not coming towards us at all. The water is moving up and down and a little back and forth; but at the moment that the wave breaks at our feet, the same drops of water, which we first looked at out at sea, are still where they were and as far away as ever. If you can once thor-

oughly grasp how a wave moves, you will find all sorts of things to do with science, such as sound, light, electricity, much easier to understand. And so we will begin by making some little models to help us to see what a wave really does when it seems to come towards us from out at sea.

First of all get a piece of cardboard and colour it black. It should be about six inches long. With a pair of scissors

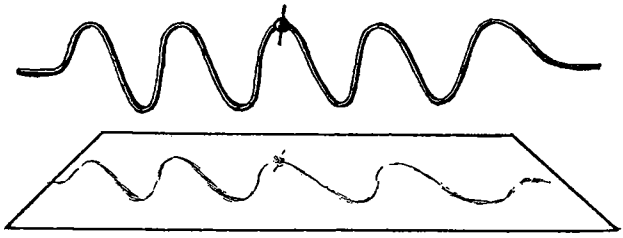


36

or a sharp knife cut it into the shape in the drawing (Fig. 36), like a comb with square teeth. Then get a piece of glass about a foot long and three inches wide and paint it on one side with dark enamel paint. Take a nail and scratch a wavy line as you see here.

When these things are made and dry, hold the glass up to a light and put the comb against it and between you and it. Then, keeping the glass still, move the comb

backwards and forwards along the glass. What do you see? The parts of the scratched line not covered by the teeth of the comb let the light through, and you see what looks like spots of light moving up and down, and the whole thing looks like a wave moving on towards one end. Now that is exactly the same as a wave at sea. You know quite well that the line of dots of light are not really moving towards one end of the glass and away from



This will help you to understand how a sea wave moves.

37

the other, for you are holding the glass quite still, but it certainly looks as if they were.

Now we will make another very simple piece of apparatus so as to study how a wave really does move. Take a piece of wire and bend it by winding it round any convenient piece of wood. Take it off the wood and draw it out into a shape like the one in the picture (Fig. 37). Leave the two ends straight so that you can twist them with your fingers. Hold this wire by the ends over a sheet of paper and let a light shine on it from above. Now twist it round and round between your fingers and watch the shadow. The shadow seems to be moving towards one

of your hands and away from the other, and when you twist the other way the motion seems to be reversed. And yet all the time, as you are holding your hands quite still, you know perfectly well that the wire is not moving sideways at all.

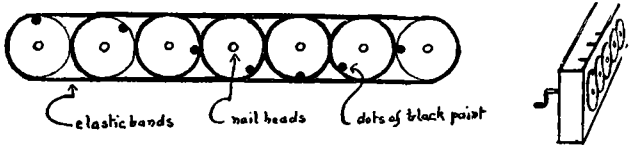
Next take a piece of wax or anything else that you can make stick to the wire. Roll it into a little ball and watch its shadow as you twist the wire. You will see that whereas the wire shadow looks as if it were a wave moving from left to right, the wax ball shadow is just bobbing up and down, up and down.

As you twist the wire the wave seems to lift the ball and drop it again and go on until it breaks against your finger. Now consider well what you have seen. It looked as if the wire must be moving towards your finger, and yet you know perfectly well that it was doing nothing of the sort. Each bit of the wire was simply moving up and down just as the wax ball was moving up and down. It is exactly the same with a sea wave. It looks as if it were advancing towards the shore, but really all that is happening is that the drops of water of which it is made are going up and down. The first drops of water that you saw, when you chose the particular wave out at sea, are pretty well just where you saw them first, even when the wave is wetting your feet.

II. HOW TO MAKE A MODEL OF A SEA WAVE

This may seem very simple to you now, and yet it is surprising how many people do not get even as far as this in understanding a wave.

Let us make a working model of a sea wave. Get about a dozen little wooden wheels. A checker set would be very suitable. Stick a nail through the centre of each one. Get or make a thin wooden box with quite smooth sides and long enough to hold all the wheels when spread edge to edge. It should be very shallow, as in the smaller picture (Fig. 38). Bore holes in one side of the box so that, when you put the nails through, each wheel is just touching the next wheel. If the nails can go through to the other side of the box it will be better. The last wheel must have a



A simple model to show how sea waves move

38

piece of bent wire to form a winding handle as in the smaller picture.

Now paint a black dot on the outside of each wheel and arrange them each a little farther round the circle than the last, as they have been drawn here. Take some elastic bands and stretch the first band round the first and third wheels, the next round the second and fourth wheels, and so on all down the line. Now when you turn the handle all the wheels will revolve and if you watch the black dots you will see a perfect model of a wave motion. Imagine the black dots to be drops of water; this is how they move in a sea wave, round and round in a circle, forwards, down,

upwards, backwards, but never on and on towards the shore.

When you come to think of it, it could not be that the waves come towards the shore, or in time they would come right inland, or if the wind was the other way they might move away from the shore and leave miles of sea bottom high and dry!

But if you watch a piece of seaweed on a wave, especially if the water is deep and the shore not a shallow sloping one, you will see that the weed is moving in just such a circle as in your wave-motion model. Of course, if there is a good deal of wind, the weed and the crest of the wave will be blown on towards the shore by the wind, but that has nothing to do with the wave motion.

There is another thing you will see, if the shore is a sloping one with the water getting shallower and shallower: the sand puts a break on the underneath part of the wave and pulls the whole wave over. As we say, the wave breaks and becomes a breaker. And that is why seamen know from the "breakers ahead," that there is a piece of shallow water; the white tops of the waves are being pulled over by the sea bottom. If the wave is not a very big one it may not actually break, but it will be slowed up and get crowded nearer and nearer the others coming after it.

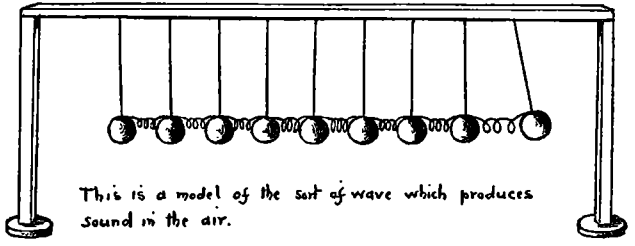
Wind and sloping shores may hide from you the true nature of a wave, but next time you are in your bath, float some little piece of paper on the surface and make a few waves. The paper will move up and down while the waves hurry from one end of the bath to the other.

But it is not simply to give you something to think about

lazing by the sea, or to help you pass your time in your bath, that I am telling you all this about waves. It is because we cannot begin to understand what light or sound or X-rays or radioactivity really are, until we have got a clear idea of a wave. So important is the wave for true scientific knowledge that we should make one or two models of different kinds of waves. So begin by splashing in your bath and sitting by the seashore, and then, when you have seen all you can, get out some tools and set to work as follows.

III. MODELS OF SOUND WAVES AND LIGHT WAVES

For the first model wave we shall want about twenty balls; old golf balls would be splendid, but if they cannot be had



39

it is quite possible to make the balls out of clay. Then we must buy a few feet of brass spring, strong enough to stick into the balls like a pin and to stop in them. We must also make a frame like the one in the picture.

I think you can see from the drawing (Fig. 39) how the

frame is made. You need not make it in the same way, for all that is necessary is to have some firm horizontal bar from which to hang the balls. They must hang from equal lengths of string at a distance from one another of about the diameter of the ball. Cut the spring into short lengths and join each ball to its neighbour with a length of spring.

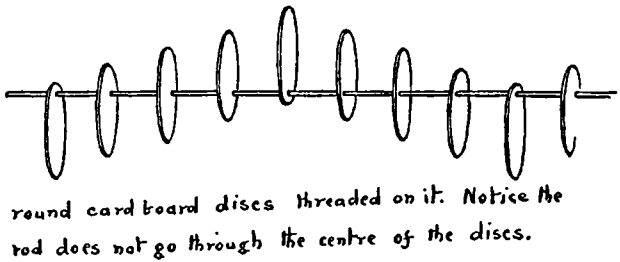
The model is now ready to work. Draw the end ball outwards towards the post of the frame and release it. Watch the movements of the balls. What do you see? First one, then the next ball takes up the motion until each one has started to swing backwards and forwards like a little pendulum; but along the line of the balls you will see another sort of motion quite different from the to-and-fro motion of each individual ball. It is like the contracting and expanding along the body of a moving snake. This is a true wave made by things moving back and forth in the direction in which the wave is going.

That is to say that it is not quite the same as the sea wave which is made by the drops of water revolving in little circles, up, forwards, down, back. A wave of the sort we have been making is called a longitudinal or lengthwise wave, because the pieces of which it is formed, our golf balls, are moving back and forth in the same line as the wave itself is moving. Now all sound is a wave movement of this sort. We are going to see soon that our model is nothing less than a model of the invisible machinery, whereby all audible things are made known to our minds through the ears.

But before we go into this let us make one more model of a wave. This time the model is a little complicated to

make and you will be able to follow just as well from the drawing, unless you particularly like making models.

First of all (Fig. 40) there is a long rod of iron or of brass, like a stair-carpet rod. On this as a shaft must be fixed a number of circular cardboard disks. The shaft is not to go through their centre, but through a point about halfway between the centre and the circumference. These disks are to be arranged as you see in the picture, each one


A long rod like a straw carpet rod with thick
round cardboard discs threaded on it. Notice the
rod does not go through the centre of the discs.

40

a little more round from the position of the first one, which is fixed so that the point on the edge nearest to the shaft is uppermost.

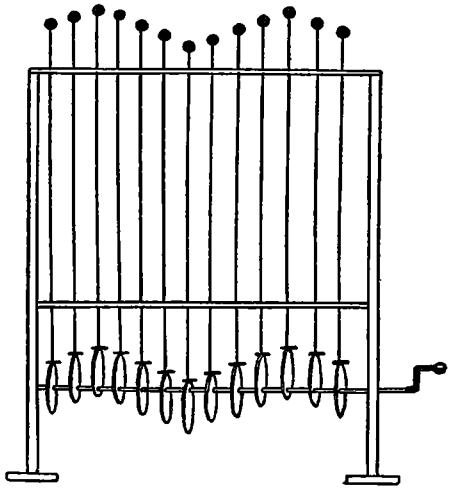
Next there is a wooden frame into which the shaft is fixed, and a handle is added to the shaft at one end.

Through both the cross-pieces above the shaft holes are pierced, one above each disk.

Next a number of rigid wires must be got, one wire for each disk, and having at one end a little black ball and at the other a smooth support which can rest on the edge

of the disk and slide nicely when the disk moves. These wires are to be threaded through the holes in the two cross-pieces which must be big enough to let them slip up and down easily.

When all these parts have been assembled the model will look as in the drawing (Fig. 41), and now when you turn



41

the handle, the wheels will push up the wires and let them fall one after the other and the balls will move in a wave motion. But there is one great difference between this wave model and the first. The balls move up and down in a direction across the direction of the wave; while with the balls in the first model, their motion was in the same direction as the wave they formed. So our new model

is a model of what is called a transverse wave because the motion of the particles making it is transverse or across the line of the wave's movement.

You will see how important that is when I tell you that all light consists of transverse waves set up by something, though what we will not say at present, vibrating in a direction transverse to the motion of the wave. And so our model might be regarded as a model of a wave of light, just as the last one was a model of a wave of sound.

And so we have made three models of waves. In the first the particles whose movements make the wave move round in circles, and this is a model of a sea wave. The second one has particles moving back and forth in the line of the wave and this is a model of the sort of wave which makes sound. The third one has particles moving up and down in a direction across the line of the wave, and this is a model to show how something, we know not what, moves in order to make the wave which, when it enters our eyes, we call light.

Now perhaps you have already been saying something like this: "It is all very well for him to tell me that, but how on earth can anybody know that sound and light are really waves? After all, I can see a sea wave and I can make out the roundabout motion of the drops of water which form the wave; but how can I see sound waves and light waves?" You are quite right, "seeing is believing." And we must certainly work out some way of seeing these other waves if waves they be.

One of the first reasons men had for calling sound and light, wave-formations, was that sound and light behave

very much as waves in water behave, and so we will begin by seeing something more about the way in which water waves behave, and then asking ourselves if this behaviour is not so like that of light and sound that we must believe that these are waves too.

IV. THE AMAZING HISTORY OF THE SPLASH OF A DROP

First of all, how are the ripples and waves in water started? You can see that for yourself very simply next time you drink a cup of coffee or take a bath. We have all seen how a drip of water starts ring after ring of ripples over the surface of the water or the coffee. They go so fast that you can hardly see them, and when they get to the edge they at once race back to the centre once more. It is surprising what a lot of time one can spend leaning over the side of a canoe on a summer day, watching the ripple from the drops of water at the ends of one's fingers.

But as is often the case, most of the interest and the beauty of this common thing is hidden from us because it happens so fast that our eyes cannot follow it. Fortunately, we can bring the camera to our rescue. Let us look at some very wonderful photographs of what happens when a drop splashes. They were taken by a man named Arthur Worthington, with some very delicate apparatus. He wanted to see what happened to a drop every thousandth of a second or so from the time it struck the water surface. To do this he arranged his apparatus so that it would drop any number of drops of exactly the same size, speed, and general behaviour; then he photographed the first drop as it hit

the water, the next a thousandth of a second later, and so on. In this way he had the whole history of a drop of water and its splash in the photographs on Plates II and III.

In the first photograph we see a drop of water falling through the air towards a glass of milk. You will notice that the drop has lost its round shape under the action of gravity, and you can see how near it is to the surface of the milk from the shadow it is casting. No. 2 is the very moment at which the drop plunges in. It seems to have broken a hole in the surface and there are what looks like folds of the milk pushed backwards. No. 3 is a photograph taken seven-thousandths of a second later. Try to get some idea of how little a piece of time seven-thousandths of a second is. Say the words, "One I'm counting," at a medium pace; that will be just about a second. Now imagine saying, "One I'm counting," a thousand times in the same time as you have taken to say it once. At that pace you would have said the words only seven times between No. 2 and No. 3. You will see that the drop of water has completely disappeared in the centre of a sort of crown, hollow on the inside and with spikes growing up from the crest. At this moment the milk making the crown is rising up into the air.

No. 4 is when eighteen-thousandths of a second have passed; the spikes have turned into round knobs and the whole crown is preparing to fall back towards the surface of the milk again. No. 5 is fifty-thousandths of a second after the beginning, and now all that is left of the crown is a thick uneven ring of milk still standing above the proper level and still with a hollow inside, rather like the crater

of a volcano. The whole thing looks a little like one of the mountains on the moon.

No. 6 is the state of affairs sixty-four-thousandths of a second from the first bump, and now a most interesting thing has begun to happen. We can still see what is left of the crown as a thicker ring than before, falling towards the proper level of the milk, but in the middle is a new lump appearing and rising upwards to the skies. Notice especially that this lump has got some black marks on it. These marks come from the lamp black that fell with the original drop of water. They are part of the apparatus used to release the drops at exactly the right time and they show that the central lump now rising out of the milk is mostly the original drop of water reappearing.

No. 7 is the situation ninety-three-thousandths of a second after the start. The time that has passed is still so short that you would have to say, "One I'm counting," ten times in a second, and then the time taken to say it once would be a little more than the time the drop has taken to fall so far. Now there is a tall column rising in the centre like a monument, and you can see that this column has among other things pushed all that is left of the crown outwards, and that this crown is now moving like a slightly raised ridge along the surface of the milk.

No. 8 was taken after twice the interval that passed between the beginning and No. 7; that is to say after two-hundred-and-fourteen-thousandths of a second, which is still a good deal less than a quarter of a second. Now things look very different. The tall column has sunk down again towards the surface, and its topmost part has broken off into

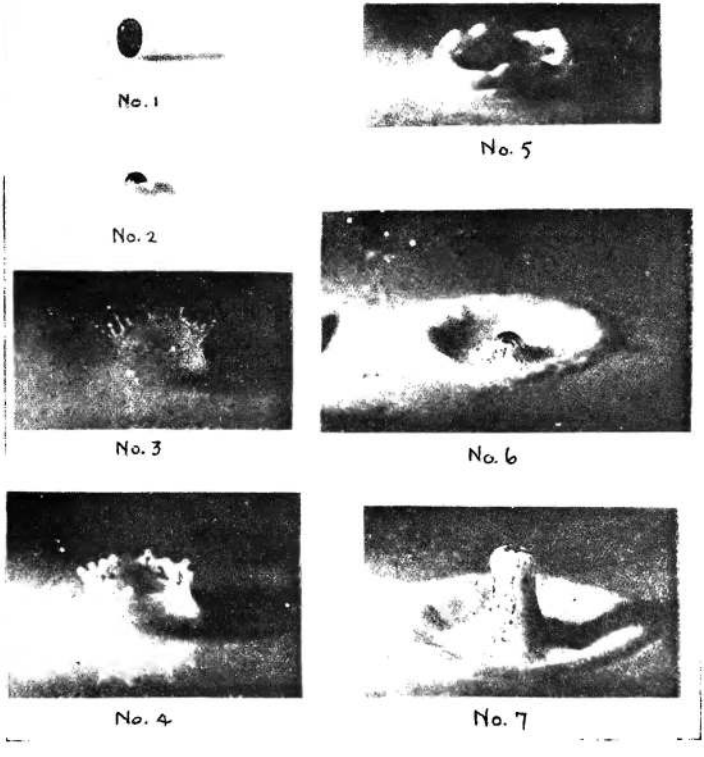


PLATE II. THE SPLASH OF A DROP

No. 8

No. 9

No. 10

No. 11

PLATE III. THE SPLASH OF A DROP (CONT.)

a ball, poised above the surface, and about to bury itself beneath it. All round is an almost flat ring spreading outwards over the surface and slightly raised above the surface, as you can see from the shadow it casts on the right-hand side.

Twenty-three-thousandths of a second later we have photograph No. 9; the ball is almost buried and it is repeating the story of the original drop; for round it is to be seen the beginnings of a new crown, while outside the new crown is the original one, turned into a wave. If you took a very large saucer and put a smaller one inside and then put the end of a sliced orange, skin side up, in the middle, you would have a good model of the state of affairs at this moment.

In No. 10, which was taken five-thousandths of a second after the last picture, the ball has sunk out of sight and we are back to the same state of affairs as we saw in No. 4, except that there is the outside ring from the first crown; and so we get at last to our final picture, No. 11, where once more we see a rising column in the centre ready to repeat the story all over again.

All this has taken less than one-third of the time you take to say, "One, I'm counting." Look carefully at this last picture, for now we can see the first two waves well under way, and we are able to understand what it was that started them off, if we consider the whole story. What did the falling drop do to the milk? First it pushed down the part onto which it fell. Then this forced a part of the surrounding milk above its ordinary level into a crown; next the crown tried to push down, and the centre depressed part

tried to push up, and they both overdid it. And so for some time various parts of the milk found themselves too high or too low and struggling to get back to their proper level, always overstepping the mark, however, and having to try again. And all this gives us a very clear idea of what starts a wave.

A wave is started when there is some material which wants to keep in one particular shape and which tries to prevent being pushed out of that shape by any interfering thing that may come along. Water, for example, wants to have a flat surface and tries to get one back if stopped from having one. Compare what would happen if you tried to dig two holes, one in the sand and the other in the sea. You could do the first quite easily, but you could not do the second. Why? Because water wants to keep a certain shape and resists your effort to put it out of shape and sand does not.

Or compare what happens if you drop a ball into wet sand and into the sea. The sand is dented by the ball and stops dented, but the sea soon covers up the hole in exactly the way we have seen happen with our drop of water and the milk.

Or try pulling out a piece of chewing-gum and a piece of elastic. The first will stay the length it was when you stopped pulling, or break in bits; but the elastic gets back as soon as it can to its original length.

To put it briefly: a wave is set up in any elastic medium when that medium is pushed out of shape and tries to get back to its original shape once more. The sand and the chewing-gum are not elastic, the elastic and the water are.

And now I am going to leap ahead for a moment so as to give you something to think about. Clap your hands. What happens? You hear something. But what has happened to make you hear? *You have made a splash in the air.* When your hands came together you pressed the air between them closer than the molecules care to be, and they rushed out and banged into the nearest molecules around them; and for an idea of what happened next just look back at the model in Fig. 39, remembering that all the molecules of air are like completely elastic balls and that they insist upon keeping a certain distance apart and getting back to that distance as soon as possible when pushed out of it. What we call sound is our ears detecting that a wave has been set up in the air round us by something upsetting the molecules and trying to push them out of the positions they insist on taking up. But to this we will return later.

Glance once more at our pictures of the splash of a drop. Between the first and the last there passed, as we have said, less than one-third of a second. It is just one example of the beauty and magic of everyday things hidden from us because our eyes cannot follow them fast enough. One of the greatest gifts of science is instruments to reveal hidden adventures in common things.

V. THE STORY OF WAVES

Let us now turn to the photographs on Plate IV and V. As you will see, these are photographs of the ripples themselves. These photographs were made by disturbing the surface of a liquid with a tuning-fork. A tuning-fork is a

piece of metal that can be made to vibrate either by hitting it on some hard surface or by electricity. It always vibrates a certain fixed number of times a second, and therefore, as we shall see later, it always gives out the same musical note. That is one of its many uses, to act as a standard by which we can judge whether a musical instrument is in tune or not. Here (Fig. 42) is a picture of a tuning-fork.

A tuning fork

42.

To make these pictures a tuning-fork was used so as to get a constant and unvarying splash in the liquid. We are going to try and make some of these experiments ourselves in a moment and all that I want to do now is to give a very simple description of each photograph and to point out little details which are going to come in useful later.

In Plate IV, No. 1, you see the waves start out from the point of the tuning-fork and spread in all directions until they hit against a wall, which you can see below and to the right of the starting point. You will also see that when the waves hit the wall they start back again towards the point from which they first started. So there are two sets of rings going in opposite directions. Now notice two things about these sets of rings: first of all are the reflected rings which are going back towards the starting point, the same size, bigger or smaller than the first set of rings? And second, notice the cut-up look on the surface of the liquid where the two sets of rings pass through one another.

In the second photograph on this same plate you see

this even better. Notice, too, the "shadow" behind the barrier which stops the waves from passing on. At the top of the barrier you see a pattern of very dark and white places where the waves are passing through one another, as the reflected set finds its way back to the starting point again.

In the third photograph you see what happens when a curved wall is put in the path of the waves. You should repeat this experiment on your own later, but while you are looking at this photograph now, I want you to think of what happens to light if you put a curved reflector behind it. Also try to think what difference there would be in this photo, if instead of the barrier being curved it had been a long straight wall. Looking at the reflected waves in the first two photos, try to sketch in how the waves would have been reflected then.

The fourth picture shows something quite different, which will be most important later. To take it the tuning-fork was moved gently down towards the bottom right-hand corner of the picture. Now the thing to notice most carefully about this is that the waves are not making perfect circles any more. If the tuning-fork had been kept still, perfect circles would have spread out in all directions from it. But now that the tuning-fork is moving we see that the circles are squashed, so that there are more of them in the direction in which the fork is moving than there are in the direction from which it is moving. If you do not see this by just looking at the photo, make a mark at equal distances from the fork, one in the line of its advance and the other in the path it has already passed, and count the

number of rings between these two points and the fork. You will find more rings in the first length than in the second.

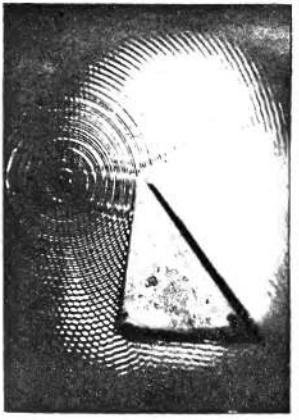
Now this may seem a little dull, but it is really very exciting. Because of this squashing up of the rings in the direction in which the original splash is moving, we can tell that some of the stars are rushing towards us at hundreds of miles a second and other stars rushing away from us just as fast. Every day in any laboratory quite dull things like this photo of what is called the Doppler Effect may turn out to be the most exciting clue of all.

We now turn to the next plate, where four more wave pictures are to be seen. The first shows a wave that has been made at the bottom of the picture. You see two straight lines from left to right; these are the edges of a piece of glass that has been sunk into the water so that the part of the water between the two lines in the picture is shallower than the rest. What happens to the waves when they get to this shallow part? You see them bent outwards. Turn to two other pictures in this book, Fig. 51 and Fig. 53. We are going to see that these three pictures seeming to have nothing to do with one another are really closely connected.

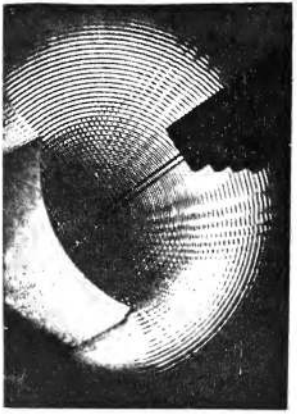
The second photo has a shallow piece in the water to the right, where you see the faint outlines of a triangular piece of glass sunk in the water. Again you see how the waves are bent as they pass over it, and this time I want you to bear in mind that there is a connection between this picture and Fig. 28, which you have already seen.

The next two pictures once more show how two waves interfere with one another when they pass through one

No. 1



No. 2



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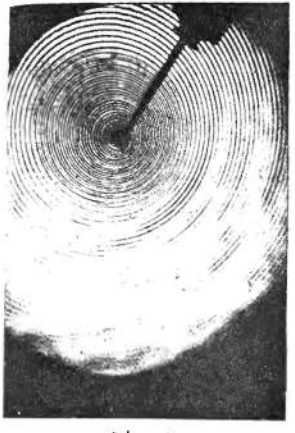
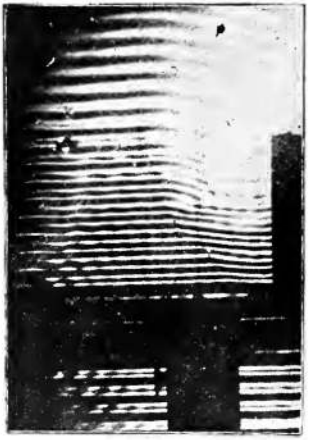


No. 4

PLATE IV. THE STORY OF WAVES

No. 1



No. 2

No. 3

No. 4

PLATE V. THE STORY OF WAVES (CONT.)

another. This time it is not one wave and its reflection after it has hit a barrier, but two separate waves starting off from two separate splashes. Again notice the pattern of light and dark that is made by them, and notice that the light and dark are more noticeable in the second picture where the two splashes are closer together.

All these photographs have been chosen because they give valuable clues in our search for the truth about matter and the making of the universe.

VI. MAKING A SEA OF OUR OWN TO STUDY WAVES

And now it is high time to try and see some of these things for yourself. I have told you the sort of things that can be seen, and now we are going to see them, and before we begin I want to confess that that is really not a good thing to do. If you decide to train yourself to be that special kind of detective called a scientist, you will have to learn *not* to think you know what you are going to see before you try to see it, or you may very possibly see a number of things that are not there.

Perhaps you have read in Shakespeare's "Hamlet" the passage where the old man Polonius is being teased badly by the prince Hamlet. "Do you see," Hamlet asks him, "yonder cloud that's almost in shape like a camel?"

"'Tis like a camel indeed!" answers the old man.

"Methinks it is like a weasel."

"It is backed like a weasel."

"Or like a whale?"

"Very like a whale."

Polonius was able to see the cloud as anything Hamlet suggested, and that is too often what we do. But in this case it is really difficult to see what these rapid ripples and waves are doing, and it becomes easier to see when once we know what to look for. And to make sure that we do not miss anything I am going to repeat several things I have already said.

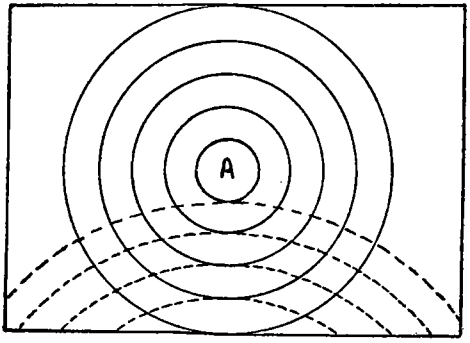
Let us make a small sea of our own, in order to study sea waves. Get a shallow dish about two feet long, eighteen inches wide, and two inches deep. It must have a perfectly smooth bottom and it must be enamelled white; also be very careful to see that the dish is lying quite level, so that when it has water in it the water is at an equal depth all over.

We shall also want a can, about three inches in diameter, a piece of wood an inch or so shorter than the width of the dish, a piece of window glass twenty inches by four, a triangular piece of glass with sides of about six inches, a circular piece of glass six inches or so in diameter, a piece of barrel hoop bent into a semicircle which can be fitted into one end of the dish.

Having got together all this simple apparatus, we have to fill the dish a fifth of an inch deep with water coloured with ink. This liquid is to be as dark as it can be without making it impossible to see the white bottom clearly through.

Now we are ready to make our waves, using the can. We can make any number of circular waves simply by putting the can down in the sea or lifting it out again. You will see at once the advantage of the inky water over the

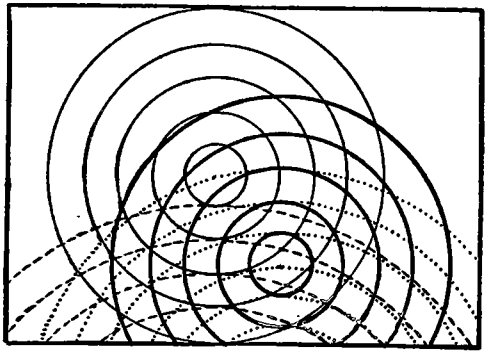
white bottom, for the crest of the wave will be thick enough to obscure the bottom altogether and the trough thin enough to let the white stand out clearly; so that we see a series of dark rings hurrying across the surface of our sea.


A
When you make a wave start from A it hits the edge of the sea and starts back again as if from this point B right outside the sea. Look at this drawing and then make the wave for yourself.
B

43

First of all make some simple waves by dipping in the can near the centre. Watch what happens when these waves reach the side. They seem to start back again in a slightly changed form. Look at this drawing (Fig. 43) of a wave that has hit the side of the sea and has come back again towards the centre. When the wave gets to the starting point again, it is twice the size it was when it started. That

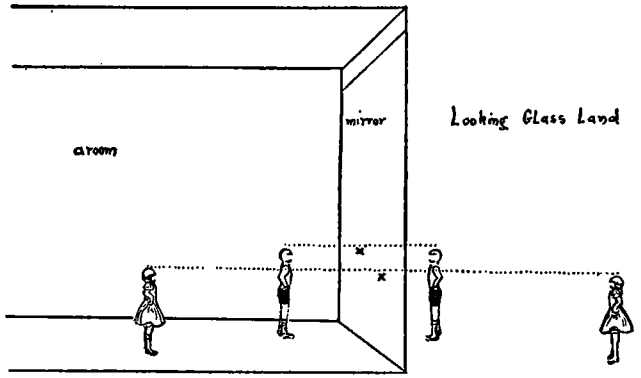
is to say, it looks as if it had started from a point outside the sea and at the same distance from the edge as the original wave really did start from. The drawing makes this quite clear.



44

Now make two waves from two separate points, one nearer the edge than the other, as in the next picture (Fig. 44). The two waves, when they start back from the side, both look as if their starting point was outside the sea and at a distance equal to that of the original waves' starting points. This, too, is much easier to draw than to put into words, so look at the pictures again. And now I want to tell you why I have pointed this out to you.

If you can find a large mirror, stand in front of it with a friend and let the friend stand nearer the mirror than you and to one side. Look at your reflections. They look as if your friend's reflection was coming from a point behind the mirror, nearer it than your reflection. Does it occur to you that this is rather like the waves? The re-



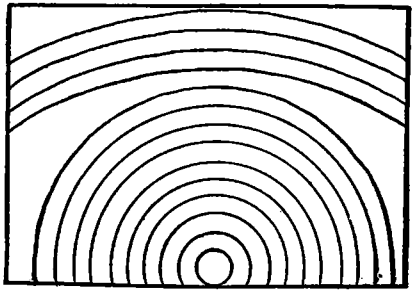
The crosses, mark the points on the mirror where the reflections are seen, and the dotted lines show how the reflections seem to be as far back in Looking Glass Land as the two people are standing away from the mirror.

45.

flection of your friend and yourself seem both to come from points in Looking Glass Land, as far back as the two of you are standing in front. The diagram of your reflections in the mirror is just the same as the diagram of the waves and their reflections. Is it just a coincidence or does it mean that light reflections have something in common with waterwave reflections?

When you have become experienced in making and

watching these waves, take the first piece of glass and sink it at one end of the sea. There should be only just enough water over it to make it thoroughly submerged and no more. Now, when you make a wave, watch what happens when it reaches the shallow part of the sea. It is slowed up and lengthens out and is less curved than it was in



A rough plan of how a wave changes shape when it gets to a shallower part.

46

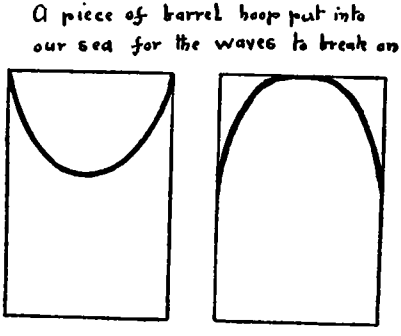
the deeper part of the sea. Fig. 46 gives a plan of what happens.

Next take the piece of wood and make waves by putting it in and out of the water, holding it at an angle to the piece of glass, as shown in the photograph Plate 5, No. 1, and watch what happens to the waves as they reach the shallows.

Next submerge the triangular piece of glass as you saw in photograph No. 5 on Plate 5 and make waves. What happens now when they pass over the glass? Turn to the drawing No. 28, of a beam of light passing through a

prism. Is there not something similar between the behaviour of the wave and the beam of light? In both cases, instead of going on in the same direction they are bent and spread out.

Finally put the piece of barrel hoop at one end of the sea in the way you see it in picture No. 47 and send waves into it with the straight piece of wood. Watch how they come out again. Now put the hoop in the other way,



47 48.

as in picture No. 48, and do the same thing all over again, watching what the hoop does to the shape of the wave.

Now think for a moment of what happens when you look into a mirror curved like the piece of hoop. Ask somebody to let you look into a convex mirror and a concave mirror and see what happens to your reflection. Think of your reflection as if it were a number of light waves going from your face to the glass and back again and see if you do not think that there is something very similar in the

way the mirror acts on them to the way the hoop acts on the water waves.

I am not going to say any more about this on purpose, because I want to give you the chance of doing some real detective work on your own. You have been given a hint that light seems to behave very much like the water waves, and you are to find out as many bits of evidence as you can by yourself.

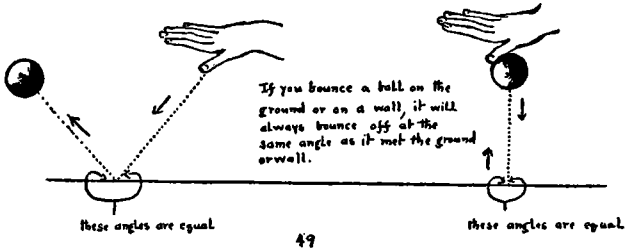
Repeat all these experiments until you have got a clear idea as to what you have really seen. It will be very interesting to write down notes of each experiment on a piece of paper. Use the drawings and the photographs to help you, and try to follow each wave and to see that they are behaving as in the illustrations.

If you want to act as scientists do, you will take a little trouble with these things, but if for some reason you cannot do the experiments just yet, I think the next section will explain to you the importance of what can be observed by doing them.

And now let us sum up some of the things that we have noticed in our experiments with waves. First of all we have seen them reflected, and we will have noticed that the reflection obeys a very simple rule; it is the same rule obeyed by a ball hit against a wall or dropped to the ground. Bounce a ball on the ground along the line that it would take if you just dropped it and it will return to your hand, but bounce it to a point to one side and it will bounce up from the ground at an angle equal to the angle at which it struck the ground, as you see in Fig. 49. It is the same with a wave of water; make a straight wave with the

piece of wood by dipping it into the water at an angle to one side of our sea and watch how the wave is bounced off the side at the same angle.

Now, having procured two long sticks, stand with a friend in front of a large mirror. With one of the sticks touch the mirror at the exact point where you see the reflection of your nose. Ask your friend to take the other stick and to touch the mirror at the exact point where he sees your nose. The two sticks will not touch the mirror at the same

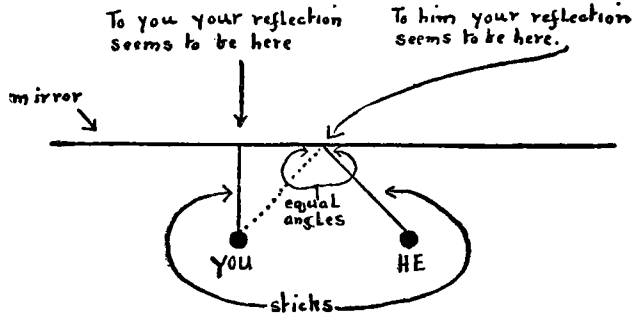

If you bounce a ball on the ground or on a wall, it will always bounce off at the same angle as it met the ground or wall.
these angles are equal
these angles are equal

49

spot. Your stick will lie along a line at right angles to the mirror if you put the other end of it to your real nose, and his stick will lie along a line at an angle with the mirror equal to that which would be made by a line drawn from where he thinks your nose's reflection is to your real nose. You can see this clearly in Fig. 50.

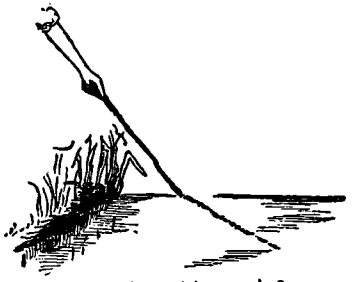
Now is not this very like the reflection of a water wave? Imagine the reflection of your nose as a ball bounced by you from your nose straight at the mirror at right angles; it bounces back at you at right angles again. Now suppose that the reflection is a wave, that something about you causes a splash sending out rings in all directions, and that

these rings or waves are reflected by a mirror back to you and your friend. A different part of the ring gets back to his eye from the part that gets back to you, and in each case it is the part that makes the same angle with the mirror as it made when it first hit. In short, light seems to behave, as far as the way it is reflected is concerned, as the waves we can see in water.



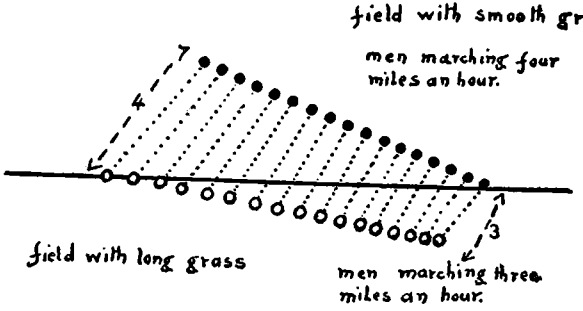
Next you have seen in the pictures and in your own experiments that when a straight wave made with your piece of wood comes to a shallow part of the sea it is bent. You see that in photographs Nos. 1 and 2 of Plate 5, and you can also repeat it yourself. We can say that whenever a wave passes from water of one depth to water of another depth it is bent. Now think what happens to a long straight stick if you put half of it in water. You have seen hundreds of times that it gets bent as in this Fig. 51. Is there anything more than a coincidence about this?

First of all why does the wave get bent in the shallower water? Think of a body of soldiers marching along as you see in Fig. 52. Each ring is a soldier and they are



Why is this stick bent?

51



52.

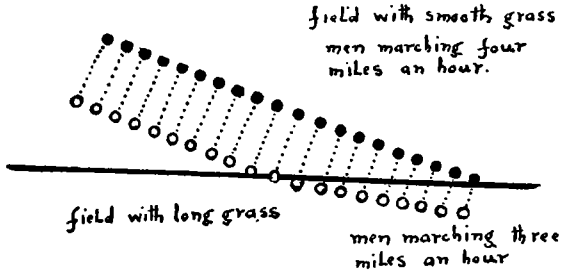
marching in a line towards a boundary between two fields. One end of the line has already got to the boundary. In the field through which they have been marching there is very smooth short grass and they have been able to

march steadily at four miles an hour, but on the other side of the boundary there is rough long grass in which they can only march at three miles an hour. The man on the right is the first to cross the boundary and at once he has to slow down, but the rest are still going at four miles until they one by one reach and cross over the boundary. By the time the left-hand man gets there the direction of the whole line will have changed. It will have swung round by the left, for the left-hand end will have been moving faster than the right-hand end and they will now be moving in the direction you see in the picture.

Now that is exactly what happens to the wave crossing over the boundary into shallower water. The end that reaches the border first is slowed down, while the other end is going just as fast as ever, and so the direction of the wave is altered. Now think of the stick in the water, can it be that it is bent because the light from it by which we see it is slowed up when it passes across the boundary from the air to the denser water? Look at Fig. 53; it is the same as Fig. 52 only it shows a moment when half the soldiers have crossed the boundary into the long-grass field and so have been walking more slowly than the other half. The line is bent exactly as the stick is bent. Do you think this can be for the same sort of reason? In short, does it not look as if light is not only like a wave in the way it is reflected, but like a wave in the way it is bent, or refracted as it is called, when passing from one medium to a denser one?

In the third place we have seen that the waves are bent

in a special way when they come in contact with the bent hoop. Instead of going back, that is being reflected in the same direction, they converge to a point. In a teacup they all converge to the centre when they hit the edge because the edge is a perfect circle. Now think of what this means. The waves all get concentrated to one spot, the focus, as it is called. And is that not exactly what light does if, in-



See how the line is bent at the boundary and compare this with the bent stick in fig. 51

53

stead of putting it up against a hoop, you pass it through a curved piece of glass, called a lens? It seems that, whatever it is, light behaves like a wave in the sea in the way in which it gets bent in or spread apart by suitably curved bits of glass. Is this a coincidence, too?

And now for our fourth interesting property of waves. Look at photographs 3 and 4 of Plate 5, as well as photographs 1 and 2 of Plate 4; you will see that two sets of waves have been made by two tuning-forks disturbing the

liquid, and you note that there is a beautiful fan-shaped pattern of light parts separated by very dark parts. This is something you can see any day on a still lake. All you have to do is to watch where two or more circles of ripples or waves pass through one another. What happens? Sometimes two wave crests come together and make a wave higher than the usual. That accounts for the darker patches. But sometimes the crest of one wave comes against the trough of the other, and then there is neither trough nor crest, for one cancels the other out.

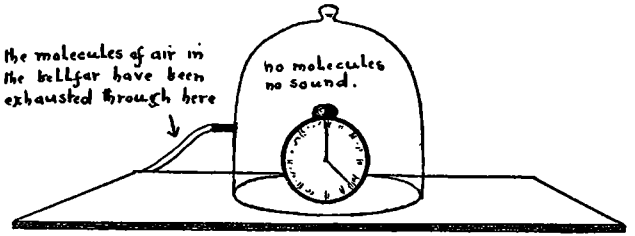
This is called *interference*, and is perhaps the most important thing about a wave. Indeed, wherever in nature we see anything that suggests this interference we are probably right in saying that some kind of wave is at work. We are going to see that because light sometimes shows the sort of behaviour that we see when two waves in water cancel out as in the photograph, scientists feel sure that light must be some kind of wave. It seemed very probable that this was so from the way in which light is reflected and refracted and acted on by lenses, but when we have evidence of this interference in the case of light we become certain. We shall return later to this question of whether light gives evidence of interference.

VII. SOUND IS AN AIR WAVE

We have now learned quite a number of important things about waves in water, and yet you are perhaps a little doubtful as to the necessity of all this for our detective hunt. Let us remind ourselves what that hunt is after.

We have learned that all matter is made up of atoms

which behave in a very surprising and complicated way, and we know that besides these atoms there is something else in the universe which causes light and X-rays and several other things. We have seen how electrons jumping from one orbit to another produce a something which takes the form of X-rays or light, and we want to know what this something is. You must take my word for it that the first step in tracking this down is to be quite clear in our minds about waves.



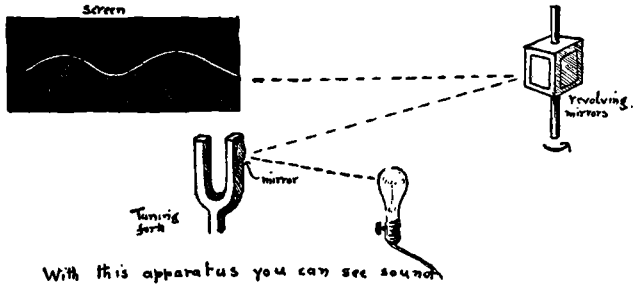
How to make an alarm clock harmless – put it in a vacuum with no molecules to pass on the sound.

54

We are now going to give up our main pursuit for a bit in order to follow a side issue which once more will throw light on our quest. Let us leave water waves and think a little about air waves.

It is quite easy to show that sound is a wave through the air. If you can use a chemical and physical laboratory, you will be able to get hold of a vacuum air pump. Here in this drawing (Fig. 54) is an experiment which shows that there can be no sound in a vacuum. An alarm clock is

put inside a bell jar ready to go off in a minute or so. The air is now exhausted by means of a pump. Fewer and fewer molecules are left inside. You wait for the alarm to go off, but you do not hear a sound. Let the air in and take out the clock. Test the winder of the alarm. It is completely unwound. Then the alarm did go off, but without a sound. Why? Because the molecules of air were exhausted from around the clock and so there was nothing to carry the



55.

sound. For sound is vibration of molecules and if there are no molecules to vibrate there is no sound.

Next get a dinner gong and tie a very light and small ball of pith or a wood splinter to a piece of thread; hit the gong and hang the ball so that it just touches the gong. What happens? The gong bounces the ball away from it. The gong is vibrating and therefore making anything near it bounce away or vibrate, too. This is just as true of the invisible molecules on each side as it is of the ball on the thread, only the molecules, being smaller and more elastic, set up a vibration which is passed from molecule

to molecule until it reaches the molecules in our ears. Look back at the model of the golf balls (Fig. 39) and you will see what is happening to the molecules of air round the dinner gong. They are banging into one another and setting up a wave.

Next let us try to see the wave that is set up by a sound. Here (Fig. 55) is a picture of the simple apparatus with which an English scientist, Dr. J. A. Fleming, made air waves visible. You see a tuning-fork with a little mirror on one of its prongs. The light is playing on this little mirror, and is reflected by it onto a kind of square box, with four sides, each of them another mirror. This box can be made to twirl round in the direction of the arrow.

At the back there is a screen, so arranged that a spot of light falls onto the screen after being reflected from the tuning-fork mirror onto the square box.

Now when the tuning-fork is set vibrating the spot of light on the screen moves up and down like a streak of lightning; and, when, as well, the box is twirled round, you see on the screen a wavy line as in our picture. This wavy line is formed by a tuning-fork vibrating at a given rate, and if a different fork were used, giving out a different note, then the wavy line would be different. In fact, the line is a true picture of the sound, and from it we could guess the sound that made it if we knew sufficient details about the apparatus. In short, we have here a simple example of how it is possible to turn a sound into something else, in this case a streak of light, and if we are clever we can turn the streak of light back into a sound. That is the sort of idea that lies behind all sorts of modern inventions

such as telephones, wireless, and telegraphy. But for us just now the important thing is that it helps us to see that sound is a wave formation in air.

Next we can see that sound behaves very much like the waves in water that we have been studying. For example, let us consider an echo. An echo is a reflection of sound and we can see that it behaves in exactly the same way as a reflected water wave.

For instance, take the echo in the great Transport Building at the Chicago World Fair. The roof of the building is a huge dome, and instead of its being supported by pillars and arches inside, it is "sky-hung" by means of cables to steel masts outside. Thus there is nothing to spoil the most perfect echo in the building below. If you bang a piece of wood on the floor immediately below the highest part of the dome, the sound waves rush upward to the roof and are reflected back to the floor in exactly the same way as the water waves when they came in touch with the bent piece of barrel hoop. They all converge again to the point from which they came and are reflected once more off the floor to the roof and so on, ten times and more before they die down. Of course by the time these words are in print the building will no longer be empty and the echo will be spoiled.

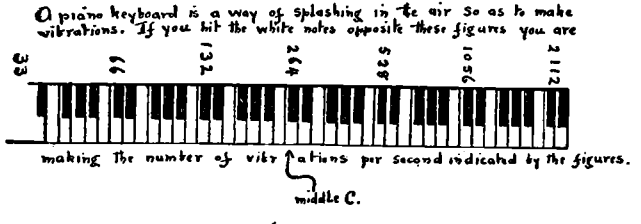
Now this is only one way in which sound waves can be shown to be exactly like water waves in their general behaviour. You can also refract them, and bend them with lenses, and change their direction, with sounding-boards, and in all sorts of ways make it clear that the air is carrying sound in much the same sort of way as water carries waves

at sea; only, of course, whereas the sea waves can only go along the surface of the water, the air waves pass in all directions equally.

But we must look especially at one way in which sound behaves like all other waves, and that is when sound shows signs of what we saw above was called interference. Why is it that we object very much to a person singing out of tune? You must have played the following game—if it can be called a game—often enough: you and a companion both sing very loudly a long sustained "ah-h-h-h," but not exactly on the same note. When you do this and if the difference between the two notes is very small, you will have noticed that instead of a steady noise of the same loudness coming to your ears there comes a series of loud beats and less loud intervals between them. You get the same effect from a piano out of tune, a beat, beat, beat, which is very unpleasant. What causes this?

Think again of the picture of the two sets of ripples on the lake. In the same way as with them the crest of one wave comes to your ear heightened, so to speak, by coinciding with the crest of the other wave; and then a little while after, because the distance between the crests of one sound wave and the other is different, the two crests do not arrive at the same time, and this produces the beat. Of course this must happen always whenever two sound waves of different lengths come through the air at once, but unless the beat comes only a few times a second the ear cannot detect it and we do not feel discomfort. And so it comes to this: that two notes sound nice together when the beat of their two wave crests, arriving together, is re-

peated so often that we do not notice it; and two notes sound bad when the crests coincide so seldom that we can detect it. So if you go to a well-tuned piano and hit two notes next one another at the same time you will not like the noise, but if you hit every third note or fourth or fifth or sixth you will like it, whereas again you will not like hitting the seventh. You will see that this is exactly what we have learned to call interference; so we have the best rea-


A piano keyboard is a way of splashing in the air so as to make vibrations. If you hit the white notes opposite these figures you are
33
66
132
264
528
1056
2112
making the number of vibrations per second indicated by the figures.
middle C.

56

son of all for deciding that sound is made by waves in the air.

Actually it is possible to measure exactly the length of the air waves which make any particular note, and there is a wave so short and another so long that our ears cannot hear them. Look at this picture of the keyboard of a piano (Fig. 56). Think of what it is a piano really does. It is a machine for making splashes in the air, splashes which behave very much like the ones we studied in our photograph. Each separate piece of ivory is attached to a wire which will make a splash sending out air waves of a given length.

Thus the note in the piano called middle C sends out

a wave at the rate of 264 to the second. Look back at Fig. 39, which you will remember is a model of a longitudinal wave; imagine that each of the balls is a molecule of air. A wave passes along them in such a way that each pair of balls get alternately closer together and farther apart than usual. If the balls moved from their nearest position through their farthest position and back to their nearest position again, 264 times in a second our ear would hear the molecules beating on the drum and we should say that the note called middle C on the piano was being struck.

Go to a piano and hit middle C; you have made a splash in the air of the right sort to make a wave of frequency 264, as it is called. Now hit the note one octave above—that is, the eighth note above middle C; you have now made a splash producing 528 waves in a second, for every note on the piano has a frequency exactly double the note eight below it. The lowest organ note is about 30 and the highest note of the piccolo flute is 4,752 per second, and between these all musical sounds are to be found.

But there are much higher sounds than these, such as the squeak of a bat, and every human ear varies as to how high a note it can hear. That is to say that one ear can detect the waves of the molecules beating on the ear drum ten thousand times a second, while another can detect them much faster. It is quite easy, too, to make detective instruments that can tell you that the air is full of waves of so high a frequency that the ear cannot register them. In fact, on either side beyond the seven octaves of audible

sound lies inaudible sound made by waves vibrating too fast or too slow to be caught by our ears.

We will do well to think of this for a bit, although it seems to have little to do with our real detective hunt, because it helps us to understand some of the clues we are now going to use.

VIII. WE FINALLY DECIDE THAT LIGHT MUST BE A KIND OF WAVE

We are now going to approach the central part of our mystery. So let us pause for a moment and put down some of the things we have found as clues.

We know that the smallest pieces of the elements are very complicated affairs made up of two kinds of electricity, the positive proton and the negative electron.

We know that there must be something else beside this because, to begin with, we *see* matter, and that means that our eyes detect matter because something comes from matter. Of course this something is called light, but what is light? Is it some kind of matter or something quite different?

We know that the electrons rushing round in the atoms occasionally jump from one path to another, and when they do this they cause a disturbance. What kind of a disturbance do they cause?

We know that, when we cause a disturbance in water by splashing, waves are produced; and we also know that when we cause a disturbance in the air another sort of wave is produced, and that when our ears detect these waves we say that we hear.

We have seen that light behaves in many ways so like other waves that we must consider it as being itself a wave disturbance of some sort, though of what it is a disturbance we have no idea. Certainly it cannot be a disturbance in the air, since most of our light comes from the sun across tracts of empty space with no air in it at all.

We have also seen that there are certain other forms of disturbance of a mysterious nature: Röntgen's X-rays, the rays coming out of uranium and radium, the heat rays. What makes these disturbances, and are they anything like light?

Now the first thing to do is to settle once and for all what kind of a thing light can be. We know that it can be reflected and refracted just like the waves in our sea bath, but can we see anything of the sort we have learned to call interference? Remember that interference shows that a thing is a wave because it is produced by the crest of one wave cancelling out with the trough of another wave. Can we see anything like this in the case of light?

Yes, we can. About a hundred and twenty-five years ago a scientist named Young showed by experiment that light was a thing which revealed the same sort of interference as you see when two sets of water waves meet. To show this you make two very small slits in a window blind and let two beams of light into a dark room. Only the light must not be ordinary sunlight, because that is made up of light waves of all sorts of different lengths and to do the experiment properly it must be light of only one length—red light let us say.

Now you let the red light into the room at two points

very close together and you let the two beams fall on a white screen. What do you see? You see a number of bright bands of light with dark bands in between them. Why is this? Because the light coming from the two slits to the screen has to pass along paths of slightly different lengths and so it happens that sometimes the crests and troughs of the two waves both come along together, while sometimes a crest of one wave and a trough of the other come to the screen together. When the first happens there is a bright band of light, and when the second happens there is a band of darkness.

Look back at the photographs on Plates 4 and 5, where you see the same thing happening with water waves, and you will see how Young's experiments seem to be the final evidence that light is made of waves.

IX. HOW JUMPING ELECTRONS SEND OUT LIGHT

We have now seen enough evidence to make us feel sure that light is caused by *something* making waves in *something*. Can we find out anything about those two somethings?

To begin with the second, in what are the waves which we call light moving? We know that the water wave moves along the surface of the sea, and we know that the sound wave moves through the air; but what does the light wave, coming across empty space from the distant stars and the sun, move through? The answer to this is the answer which must always be the most interesting of all answers to real detectives: it is "nobody knows."

We know the sort of thing that it must be; for example, it must be elastic. That is, it must resist being pulled out of shape; that much we learned from studying models of waves earlier in the book. So most scientists have worked on the idea that there must be a perfectly elastic something filling all space, saturating all matter, because otherwise it is impossible to imagine how light waves travel at all; and they have called this thing ether. But the trouble is that no kind of experiment has ever been able to show that ether really exists.

It is the sort of difficulty that excites the scientist more than any other, because he tries to build up a picture of the world without ever using any idea that he cannot explain or show to be true; and here is something that he has failed utterly to show. And scientists will never be satisfied until they have either shown the ether or found a way to explain how light travels without any ether.

That is what great men like Einstein are trying to do. Einstein has already shown how gravitation can work across empty space without any need of our inventing an ether for it to work in; and now he is trying to do the same for light.

So here is the sort of excitement that lies before any one of you who may decide to seek adventure by the way of science. Most of the earth has been explored and nearly all the big game shot, but there is unlimited opportunity and detective work still in science.

And now what about the other something—what causes the wave called light to start?

Let us go back to the pictures of atoms for a moment.

We see numbers of electrons whirling round the nuclei of the atoms, and every now and then one of them jumps instantaneously into another path. When this happens something called energy is produced or used up. We must carefully consider what the scientist means by energy. We use the word every day. We say, "Oh, I haven't the energy to read to the end of this page." We say, "You are energetic." Now when the scientist uses the word energy, he means exactly the same thing as we do. He means the power to do work. Energy is the power that matter has of doing things, of bringing about changes. Take, for example, an electron whirling round in an atom. It requires a certain amount of energy for it to keep going round; then suddenly it jumps to another orbit which does not require so much energy, just as it requires less energy for you to walk up one flight of stairs than it would for you to walk up two.

Now the great discovery about energy which lies at the beginning of all science is that it is never lost. What happens to the extra bit of energy that the electron is no longer using, because the new orbit does not require it? Here is the solution of the problem we have asked so often: the extra bit of energy no longer required to keep the electron in its new orbit is used to make a splash which starts a wave moving through the ether, and that wave is what we call light.

We can now begin to answer the question, Why do we see? Look at that wall; how do we know that the wall is there? Because, far away across empty space the tremendous heat in the sun is making the electrons in the atoms jump

from one path to another, and this releases energy from the work of maintaining the speed of the electrons. This released energy acts like a splash in the ether and starts waves widening out for ever through space. These waves are, of course, quite invisible until they hit on something. They can hit on quite different things; our eyes, and anything else. If they hit our eyes, they pass through the eyeball, which is a sort of lens to focus them, and they come against the atoms at the back of the eyeball and cause chemical changes in them. The optic nerve telegraphs these changes to our brain and we say that we see the sun in our eyes.

But what happens when these same waves, coming from the sun, break upon that wall? They disturb the electrons in the atoms of which the wall is made, and from these disturbances there are set up a new lot of waves in the ether around, and these too come back to our eyes, and we see the wall.

Just imagine what a complicated thing it is. An electron jumping its orbit in the sun, more than ninety millions of miles away, releases energy that travels along until at last it disturbs the electrons in our own eyes and enables us to see the world around us.

This will help you to understand all sorts of things that you see a thousand times every day. For example: why does a piece of metal shine when it gets very hot? Remember how we saw earlier that one of the simplest ways of making electrons jump is to heat them. The metal, as it gets hotter, shines out, because the atoms of which it is composed are being more and more disturbed. Their electrons are jump-

ing from one path to another, spilling out energy and making waves all round in the ether, and these waves come to our eyes and we see the metal getting red hot and then white hot.

Let us think what would happen to that piece of metal if it were to get hotter and hotter. First the electrons make jumps of a sort that send out waves, but waves that we cannot see. How do we know that these waves are being sent out? Put your hand an inch or two off the metal. You feel that it is hot. This heat we learned to call radiant heat in the first part of the book; it is caused by waves which are too short for our eyes to see, but our sense of heat can detect them. Next the electrons make bigger jumps and the metal begins to glow. The waves made by the electron jumps are now of the right length for our eyes to see.

Next the atoms themselves, as well as the electrons inside them, become affected and begin to move apart. The metal melts, as we saw when we read how some atoms talk, others walk, and yet others run. The metal gets even hotter and the atoms begin running and dancing with a vengeance. The metal has turned into vapour. Still hotter, and the atoms cannot bear to have so much clothing on them. They strip off first one petticoat and then another. The electron rings are broken and scattered by the heat, but to see this you would have to go to a star like Betelgeux, for we could not get such heat here on the earth.

Hotter still, more petticoats come off and now we would have to be in the centre of the sun. Last of all the final ring of electrons is split into shreds by the stupendous heat, and the nuclei of the atoms find themselves naked. The

electrons, that kept one nucleus far away from the next, have vanished, and there is nothing to prevent all the nuclei huddling together close, unbelievably close for anyone who has only seen atoms in the clothes they wear on the earth. Now we have the state of affairs which is found on those dwarf stars like the companion of Sirius, where matter is so heavy that it weighs fifthy thousand times as much as water does here on earth.

And so we see that the reason why we know anything about the universe around us is that in our bodies there are senses which can detect waves of one sort and another and that these waves are produced by energy making changes in matter. Thus our sense of hearing is a way of detecting how the energy that makes our hands clap together, for example, sets up waves in the air which beat on our eardrums. Our sense of sight tells us of another use of energy leading to wave disturbances in the ether. Our heat sense in the nerve ends of our skin tell us of shorter ether waves that our eyes miss and they also tell us of actual molecules dancing very fast when we touch anything hot. Our other two senses, taste and smell, tell us about the outside world by direct contact with molecules of matter.

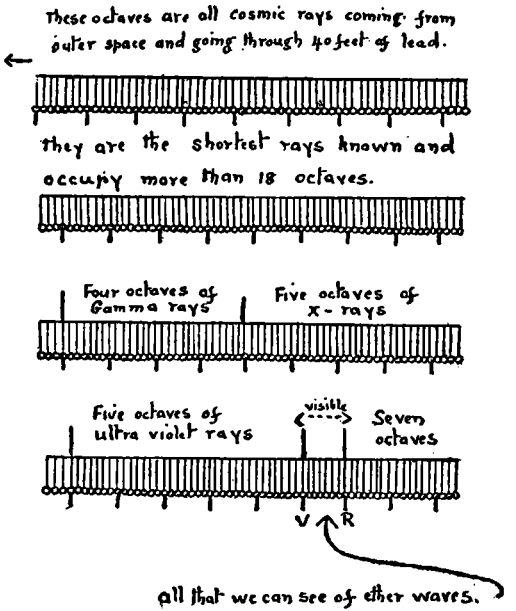
Thus some of our senses detect matter and others detect waves, and of these it is the two wave-detector senses, sight and hearing, that tell us most about the world around us. And of these two, it is the sense which detects the waves moving in the unknown mystery, ether, that is most valuable to us. Let us now look more closely at these ether waves, which we know of through our eyes as light.

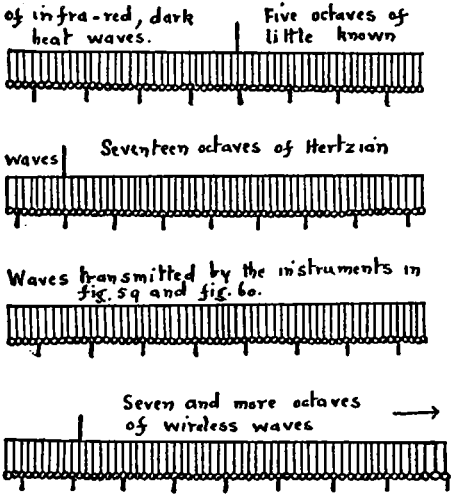
X. MAKING AN ETHER-WAVE PIANO

You remember our drawing of the keyboard of a piano and how every note is a machine for making a certain splash in the air, so as to produce a wave of a special size. Here is another keyboard (Fig. 57). It is longer than a piano keyboard, so much so that it has been drawn in eight parts and in order to make it easier to draw I have given the notes a different shape. Each round knob is a note, and the knobs with a line through them are an octave apart. Remember that in the piano any note which is an octave above any other note requires the sort of splash which will set off twice as many waves per second as are required for the other note.

Now in this new keyboard which we are constructing, every note makes an ether splash of a particular sort. Take, for example, the note marked R in the drawing. If anyone could make the machine I am describing, whenever the note marked R was played, in some way an ether splash would be made producing an ether wave vibrating four hundred billion times a second. That is a huge number of times compared with the 256 vibrations of the air wave when middle C in the piano is hit. How are we to know that note R on our ether piano has been played?

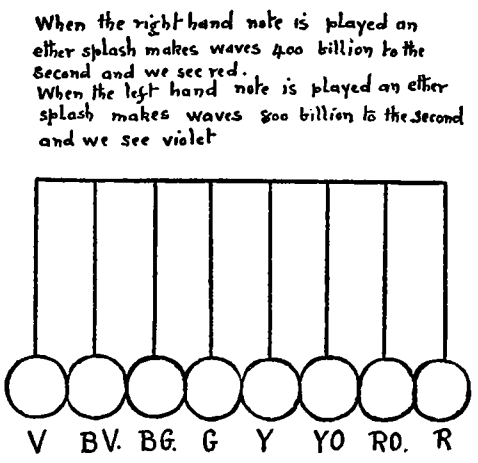
We shall know because directly the wave vibrating four hundred billion times a second has been started our eyes will see the colour deep red. In other words, whenever we see a deep red thing—the setting sun, a ripe tomato, lipstick, or whatever it may be—the backs of our eyes have


These octaves are all cosmic rays coming from outer space and going through 40 feet of lead.
They are the shortest rays known and occupy more than 18 octaves.
Four octaves of Gamma rays
Five octaves of X-rays
Five octaves of ultra violet rays
visible
Seven octaves
V
R
all that we can see of ether waves.


of infra-red, dark heat waves.
Five octaves of little known
waves
Seventeen octaves of Hertzian
Waves transmitted by the instruments in fig. 59 and fig. 60.
Seven and more octaves of wireless waves

ether waves breaking on them at the rate of four hundred billion to the second.

Now look at the note marked V on our keyboard. It is an octave above R, and when it is played an ether wave vibrating at the rate of nearly eight hundred billion to the second is set on its way, and when it reaches our eyes


When the right hand note is played an ether splash makes waves 400 billion to the second and we see red.
When the left hand note is played an ether splash makes waves 800 billion to the second and we see violet
V
BV.
BG.
G
Y
YO
RO.
R

58.

we see violet. In short, whenever we see a violet thing, we know that our eyes are having ether waves break on their cells at the rate of eight hundred billion to the second.

This next picture is an enlargement of the keyboard so that we can see one particular octave. It is the octave between note R and note V. The letters stand for the following colours—deep red, red-orange, yellow-orange, yellow,

green, blue-green, blue-violet, and violet, the colours of the rainbow, all lying between the octave four hundred billion and eight hundred billion waves per second.

Now turn back to the picture (Fig. 28) of the ray of light passing through a window and then being split up by passing through a glass prism. We know a great deal more of what that picture means now. We know that the light from the sun must be made up of all sorts of wave lengths, and that, by passing them through a prism, we sort them out into their different lengths. The shorter the waves the farther they are bent, and, since there are twice as many vibrations of violet waves as of red waves in a second, that means that each separate violet wave is only half as long as a red wave; and so the violet gets bent most of all.

But, perhaps you are thinking, what was the use of making a keyboard with so many octaves if there is only one octave of light? Let us see what lies on either side of notes R and V in our ether piano.

XI. MORE ABOUT THE ETHER-WAVE PIANO

You will remember that on the piano keyboard there are a certain number of octaves covering air waves of all sizes from about forty to four thousand vibrations to the second. That does not mean that there are not more sound waves of both fewer and more vibrations, and some of these can be heard and made use of in other musical instruments. Even when the human ear can no longer register them, there are still higher and lower notes made by waves of greater and less frequency. In the same way, as we have noted several times in passing, there are ether waves with

a more rapid vibration than violet light and with a less rapid vibration than red light; only our eyes cannot see them and we have to invent other ways of finding them out than our natural eyesight.

It is very hard to realise that these other ether waves are in no way different from light, except that they come more or less rapidly through the ether; that, if our eyes had been made to register faster or slower waves, we would be able to see them; but this is the case with every one of the waves we are going to consider now.

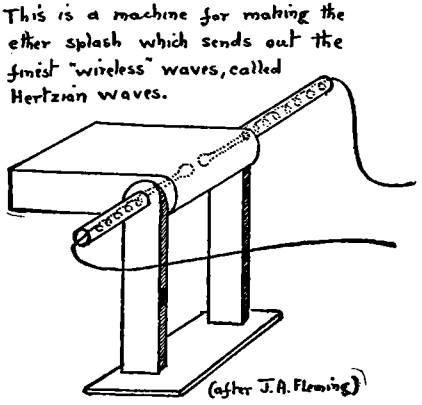
Some of them are old friends. For example, let us look at the waves that are just too slow in the frequency of their vibrations for our eyes to see them as red light. They are there all right. Pass a beam of sunlight through a prism and put a thermometer on the screen where the spectrum falls just below the last red part, where there does not seem to be any part of the split-up beam falling; you will soon know that some part of it must be falling there, because the thermometer registers heat.

And so at the part of the keyboard just outside note R there are a certain number of notes which, when played, produce less than four hundred billion ether vibrations a second, and these, although they are invisible to our eyes, are registered as heat waves by our skin or by the thermometer. And, although our eyes cannot see them, the eye of a camera can be made to register them, as we know from the photograph on Plate 1, taken entirely by the invisible light of the dark heat waves given off by an electric stove.

Of course the light waves, that we can see, also give off

heat; and that is why we have called these next waves *dark* heat waves. On our ether-piano keyboard they stretch for seven octaves.

Next to the dark heat waves come ether waves, which have not been studied or used very much as yet, but, after about five more octaves, there begin waves that have become more and more familiar to all of us through the com-

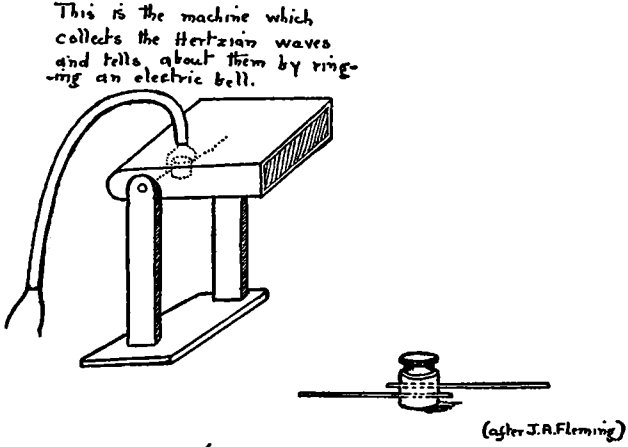

This is a machine for making the ether splash which sends out the first "wireless" waves, called Hertzian waves.
(after J. A. Fleming)

59

ing of wireless telegraphy. It was a scientist called Hertz that first discovered how to make them; and, as his experiments have proved so important, I am going to simplify an account of them from Professor J. A. Fleming's fascinating book, on *Waves and Ripples in Water, Air, and Æther.*

Look at drawing No. 59; it shows a zinc box hung

on a stand in such a way that it can be moved in any direction. Inside the box are two brass rods ending in balls a sixteenth of an inch apart. Sticking out from the stand in line with these rods are two ebonite tubes, and inside the tubes are two coils of wire joined to the brass rods



60

and having their other ends connected with some machine for making electricity.

When the electric current passes along the wires it reaches the little gap between the brass balls, and at first it cannot pass; but in time there accumulates more and more tension, until with a crackling noise the electricity begins to leap backwards and forwards over the gap.

Now look at the other drawing, No. 60. It looks much the same as the first. There is a box movable in any direc-

tion. Inside this second box there is a smaller box made of ebonite, through which two nickel wires are crossed without touching, as you will see in the little sketch to the right. A very small quantity of nickel filings are packed round these two wires. Next a long lead pipe is fixed to the outside box, with two insulated wires inside it. These wires are joined at one end to the nickel wires, and at the other end they lead on to another metal box containing an electric battery and a bell.

Now this is what Hertz discovered: when the electric current jumped the little gap between the brass balls in the first box, some kind of ether wave was set up, which passed out of the open end of the box and spread in all directions through space. If the second box was placed on the other side of the room with its open end facing the open end of the first box, these waves entered into it and reached the nickel filings and acted on them in such a way that, whereas before they would not let an electric current pass, now they would do so; and so there was no longer any gap between the wires in the second box, and the current could pass from the battery all round the circuit and ring the bell.

Hertz studied these rays very carefully and found that they were certainly waves that behaved in exactly the same way as light. Indeed, he showed they can be reflected and refracted and bent by special kinds of lenses, and in fact the only difference between them and the waves our eyes can see is that they are so long that far too few vibrations take place in a second for the eyes to be affected.

Of these Hertzian waves there are seventeen octaves

on the keyboard of our ether-wave piano. One octave only of visible light, seven octaves of dark heat waves, and now seventeen octaves of Hertzian waves. What next? Well, that can be easily answered; beyond all those octaves of Hertzian waves there are at least eleven octaves of still longer waves, which we call wireless waves, because, ever since Marconi, they have been used for wireless telegraphy and telephony.

To send these out, or, shall we say, to sound the notes on this part of the keyboard, a wireless transmitter is needed; but do not forget that, although a wireless receiver is needed for human beings to discover their existence, they are exactly the same sort of thing as the waves which are responsible for light, only they are far too long to affect the human eye.

XII. STILL MORE OCTAVES ON OUR KEYBOARD

We have taken a glance at the sort of waves that would be produced if we sounded the notes below note R, which is the downward limit of the waves visible to the human eye as light; and now we must see what happens above note V, the violet light at the other end of the rainbow.

You will remember that the way in which it was first discovered that there were invisible rays beyond the red was by putting a thermometer there and noting that it registered heat. As a matter of fact, the invisible rays beyond the red are actually hotter than any of the visible ones; and if you put a thermometer at the other end of the spectrum, in the violet part, you find that scarcely any heat at all is regis-

tered. If you put the thermometer outside the visible spectrum at the violet end, you get no rise of heat.

But this does not mean that there are no invisible and heatless rays there; for, almost at the same time as the great Sir William Herschel was discovering the infra-red rays, another scientist, named Ritter, found that if you exposed certain chemicals at the violet end of the spectrum, but outside the violet light, the chemicals were blackened by the action of invisible rays there. We now call these rays ultra-violet rays and we know a great deal about them. They stretch for about five octaves—that is to say, from the wave thirty-eight-millionths of a centimetre long, which is the end of violet light, to a wave only one-millionth of a centimetre long.

How do we detect the existence of these invisible ultra-violet rays? By the chemical effects they have on certain substances. For instance, although they are too rapid for our eyes, they are seen by the camera's eye, which is indeed very sensitive to them; so that, if we want to take photographs true to nature, we have to keep out the ultra-violet rays, or, by registering them, the camera will give what seems a false picture of nature. Actually it is not a false picture, but a more accurate one, because it is made with rays that are really there, though our eyes cannot see them.

You will remember that it was for invisible ultra-violet rays that Röntgen was looking one fine day, when he stumbled on something quite new, and called it X-rays, because he had no idea what it was.

We are able to fit the X-rays into their proper place in the keyboard of our ether-wave piano. They occupy about five octaves farther away still from the one octave of visible light; and they are made up of rays of wave length down to as small as one-thousand-millionth of a centimetre.

If you were to play a note in these five octaves, our machine would have to discharge a jet of cathode rays through a vacuum tube, as we have already seen, and these cathode rays would have to be made to hit against a little target, and then they would set up in the ether the right wave to produce an X-ray. And you would only know that the machine had played the note properly, if you put a special sort of screen, like the one Röntgen used, for the X-ray to fall on, and then you would see the screen illuminated and you would know that tiny little waves were rushing through space to produce this result. Remember once more that an X-ray is exactly the same as a light ray except that it is so much smaller and vibrates so often to the second, that our eyes are not affected by it.

Even yet there are smaller rays still to be played on our ether-wave piano. Next after the X-rays come three or four octaves of a ray called a gamma ray. This we have not yet been introduced to by name, and so we must ask for a little more information about it. Where do gamma rays come from? How do we detect them? What do they do? We must break off our story of the ether keyboard for a moment and return to that mystery which excited us a little while back, the strange thing called radium.

XIII. THE BULLETS SHOT OUT BY THE RADIUM ATOM

We saw how, after unending patience, Madame Curie extracted from pitchblende a remarkable new element, which was forever shooting out of itself some form of energy that could pierce through black paper and all sorts of thick opaque matter, through which ordinary light cannot pass. We likened it to an engine always working without needing fuel and never getting tired or out of order.

Now nothing of this sort had been known to science before; in fact, all scientists had agreed that such a thing was impossible. The great law about energy was that you could never create new energy or destroy energy that existed. To make the energy in a steam-engine you had to use the energy already existing in the coal, which was energy, as we saw in Part I, stored up millions of years ago from the energy poured through space by the sun. In fact, all that can be done, said the scientists, is to harness the energy already existing, and make it do useful work. The human body is energetic, because it uses the energy stored up from the sun by plants which it eats. Often it lets another animal store up the energy on the way for a time; thus every time you eat beef you are really using the energy got from the sun by the grass which the ox ate first.

And now here was a substance that forever shot out energy without eating anything. How did this come about?

You can give the answer from what you have already heard about atoms. Inside every atom, and protected from any interference from the outside world, is stored up all

the energy required to keep the electrons forever racing round in their paths; and for some reason or other the radium atom, unlike most other atoms, from time to time, at regular intervals, allows some of this energy to be used to shoot parts of itself into outer space. Nothing that human beings can do can stop it, and nothing can make a radium atom shoot out more of itself than the exact amount which is usual; and, moreover, no wastage seems to take place in the course of all this rapid firing; at least so people thought when they first began to study radioactivity.

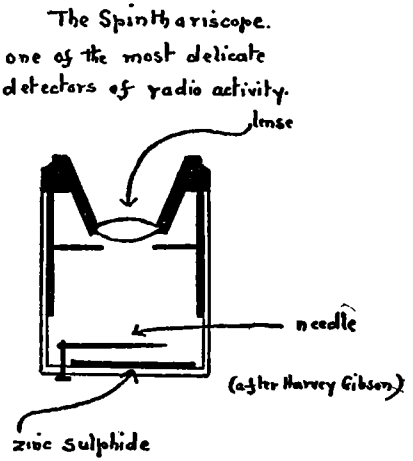
Of course the first thing that we want to find out is what these bullets, which are forever being shot out by radium, can possibly be. You may perhaps want to make a guess from what you have been reading, and say "electrons." You will be partly right, too, for some of the bullets that radium shoots out are electrons. But that is only a small part of the story.

There are indeed three different kinds of bullets shot out of radium. The first is something that is rather easily stopped. If you take a piece of radium and cover it with a thin piece of paper, none of this first kind of bullet can get through. We will call it an alpha particle, alpha being the name of the first letter of the Greek alphabet. It is the alpha particle which is able to knock the electrons off the gold leaf in the electroscope, as we read on page 73.

Alpha particles—and remember that this is just a name for something, we know not what—are shot out of radium hour after hour and year after year with perfect regularity. They make their presence felt, as we have seen, by knocking electrons off atoms that they bang into on their journey,

and when you are told that they begin their journey at the rate of about ten thousand miles a second, thousands of times faster than a bullet, you will realise what a jolt they give any atom they happen to meet.

Let us look at two ways in which these minute bullets can be seen. You will remember that the famous screen



61

that Röntgen used was covered with a chemical with a long name, which glowed when the X-rays hit it. In the same way Sir William Crookes painted the bottom of a little brass bottle with another chemical called zinc sulphide, which glows when radioactive things are brought near it. Next he fixed a needle, as you can see in Fig. 61, and put a magnifying lens at the top.

The needle had been rubbed against a tube that had once contained a chemical with a very little radium in it. You will see that the amount of actual radium that could have been rubbed off onto the tube must have been next to nothing. It reminds one of the story of how to get the right amount of onion flavour into a certain dish; the cook is to eat the onion, and breathe into a paper bag, and then the ingredients of the dish are to be put into the paper bag for one second. That is about as much radium as could have been got onto the needle.

Now if you look into this simple instrument in a dark room, you will see a glow, which you will very soon see divide up into a shower of sparks like a number of shooting stars. What is this light? It is the alpha particles banging into the zinc sulphide and knocking the electrons about, so as to produce a shower of ether waves, as we have learned can be produced by jumping electrons. In six months' time the sparks will get fewer and fainter, not because the radium has used up its alpha particles, but because the alpha particles have smashed up all the zinc sulphide. If you repaint the bottom of the box with zinc sulphide again and again, the bombardment of alpha particles will go on unceasingly and without slackening for about two thousand years.

Another way in which alpha particles can be seen, or at least their tracks can be seen, was invented by Professor C. T. R. Wilson. A piece of radioactive substance is allowed to discharge its alpha particles through a little box full of very damp air. Now air cannot carry so much moisture when it is cold as when it is hotter, and in everyday

life if the air around us is very moist and suddenly gets colder, the moisture condenses round any little bits of dust and soot and we have a fog.

So Professor Wilson arranged his box in such a way that he could suddenly cool it; for, thought he, then the moisture will seize on the alpha particles to help it to condense into drops and I can photograph the drops which will be formed all along the path of the alpha particle. In this way, although it is impossible to make a direct photograph of the alpha particle itself, it is possible to take a photograph of its footprints.

Here on Plate I are photographs of the alpha particle footprints. You will notice that some of the lines are bent suddenly towards the end. That is where the alpha particle has whacked into an atom and been pushed to one side just as when two billiard balls hit one another.

From studying what happens when alpha particles hit into atoms of known size it is possible to work out how big and heavy the particle is. And we now know that the alpha particle shot out from within the radium atom is nothing other than an atom of helium, which has lost the two electrons revolving round it. Now this is a most astonishing thing, because it means that the old dreams of all the alchemists, who hoped to change one element into another, have come true. Here is an element, radium, which changes of its own free will into helium before your eyes. An atom of radium has shot out from its own body an atom of quite a different element. What has happened to the rest of the atom? Is it still radium? No, it is another element altogether, which we shall study soon. But first we must get

back to the other kinds of bullets shot out by the radium atom. When we have studied these we shall return to this alchemist's dream come true, and see if it is also true, as they thought, that lead and other common elements can be turned into gold.

XIV. MORE ABOUT ETHER WAVES

When the alpha particles from a radioactive element are stopped by a piece of paper, the other bullets go right through. Some of these other bullets, however, can be stopped by a thin piece of aluminium. When these are studied they turn out to be something very familiar to us by this time. They are called beta particles, from the second letter of the Greek alphabet, but they are actually nothing other than electrons.

And so we can pass on to examine the third kind of bullet coming from the radium atom. It is not stopped by a thin piece of aluminium, but can even get through an inch or so of lead. It is called a gamma ray from the third letter of the Greek alphabet, and it is not a particle of matter at all; it is an ether wave, like light or X-rays, only it is even shorter than X-rays. In fact if we turn back to our ether-piano keyboard we find that the four or five octaves after the X-rays are occupied by these gamma rays.

And now we can finish up our keyboard altogether. After the gamma rays come an unknown number of octaves of shorter rays still, which seem to be raining on us from outer space in huge quantities, and so they have been called cosmic rays. These rays can penetrate through thirty or forty feet of lead, so short are they.

It is only quite recently that cosmic rays have been discovered, and great scientists like Professor Millikan and Professor Compton are still trying to decide how they are made and whence they come. It seems clear that they are raining in on the earth from outer space in all directions, but how or why is by no means so easy to understand. Some people believe that they are made by an electron and a proton—that is, as we have learned, a charge of negative electricity and a charge of positive electricity, which if they kept their proper distance would be an atom of matter, suddenly joining together and cancelling one another into nothingness. The ether splash that this would make can be calculated to be exactly the right splash to produce waves the length of a cosmic ray.

But at present, though we will have the notes on our keyboard to correspond with ether waves of this minute length, nobody knows how to play them.

Now we will glance at the whole length of the keyboard from end to end. At the far end are the longest waves with the fewest vibrations to the second. These are the wireless waves and that part of our keyboard is played with wireless transmitters and detected by wireless receivers. Next the Hertzian waves played with the kind of apparatus we saw in Fig. 59 and detected by the apparatus shown in Fig. 60. Next the octaves of heat radiation, played by the sun or any heating apparatus and detected by our own sense of touch or by a thermometer or other heat recording instrument.

Next the one solitary octave of visible light played again by the sun or any artificial light machine and detected by

our own unaided eyes. Next the octaves of ultra-violet light, played by the sun or ultra-violet lamps and detected by photographic plates and the pigment cells in our skin. Next the X-rays played by the cathode rays of a vacuum tube hitting against a target of metal as we saw in Fig. 23, and detected by screens covered with certain chemicals which show a phosphorescent glow when the X-rays fall on them.

Then come the gamma rays played by atoms of radio-active elements, without our being able to stop or increase them. And last the cosmic rays played as far as we know by matter going out of existence altogether.

Now all these waves, in spite of the fact that they are made by different methods and appear in such different forms and have such different results, are exactly the same in their general nature. They are all started by an ether splash, just as the familiar ripples on the lake are started by a water splash, and sound is started by an air splash. They all travel at exactly the same speed of about 186,000 miles in a second, and they can all be reflected, refracted, interfered with in the ways at which we have glanced in this book. They are all like the light we see with our eyes, and indeed the only difference between them and ordinary light is that we have developed the detecting instrument for that one octave in our own bodies. In fact, the difference is not in the waves, but in ourselves.

All our knowledge of the universe comes through detecting these waves. Just think where we should be without any of our wave detectors. We should not be able to see or to

hear. We might know when we were actually touching the molecules of something, but we would not know if it were hot or cold. We could taste and smell, and that is all. Doubtless we should learn to steer ourselves by the scents of the objects around us, which throw out molecules of themselves in all directions, but it would be a dull sort of world at best.

I have given you a very few simple examples of the astonishing way in which we have added to our knowledge of the universe by inventing ways of detecting all the other octaves of waves invisible to our eyes. You will find many other and more interesting things about waves if you will go to the longer books and the special researches of the scientists.

One such special research, which may be mentioned as a good example of the strange discoveries we can make through studying waves is the Doppler Effect which, as we saw earlier, tells us that some stars are rushing towards us at hundreds of miles a second and others rushing away as fast. You remember the photograph, Plate IV No. 4. In it we saw how, if the point of the splash is moving, the waves get more crowded in the direction towards which it is moving. Now when you look at a star through a spectroscope you see the Fraunhofer Lines showing up dark across the brightly coloured spectrum. As we have seen, each of these lines has its own exact place, which has been measured accurately. But sometimes in the spectrum of a star all the lines have been shifted a very little out of their proper places towards the violet end of the spectrum. Why is this?

In the photograph the waves in front of the tuning-fork seem to be squeezed together a bit more than they would be if the fork were still—that is to say, the distance between one crest and the next is less, or as we say the wave length is slightly shorter. Now when we are looking at a light wave the shorter it is, the more violet it is, and so what has really happened in the spectrum is not that the Fraunhofer Lines have shifted, but that the light of the spectrum against which we see them all looks more violet than normal. And this is because the star which is sending out these rays is approaching us at a speed which can be measured from the amount of the shift. In the same way, if all the dark lines are shifted towards the red end we know that the star is moving away from us. We know that Sirius is going away from us at the rate of about seventy thousand miles an hour, from the amount of the shift of its Fraunhofer Lines towards the red end of its spectrum.

This is just one of the amazing pieces of detective work that you can do if you learn to be a scientist. And now we must leave waves for a moment to go back and have a last look at the atom which sends out these waves through space.

XV. A FEW LAST POINTS

Before we part from our study of atoms there are two things at which we must have a quick look. First of all you will remember that we left the radium atom shooting out atoms of helium into space, and we do not yet know whether the rest of the radium atom is still radium after the helium has been shot out.

Now the story is very complicated and so I will content

myself with a short statement of the extraordinary things that are happening all the time to all the radium in the world. Imagine a lump of radium; every instant some of its atoms are shooting out helium that has lost its two electrons. Of course the helium does not have to wait long before it picks up a couple of unattached electrons from the neighbourhood, and then it is easy enough to detect it as the gas that likes to be by itself, as we saw earlier.

One of the strange things about radium is that, though you can never tell when any particular atom is going to shoot out the helium nucleus, you can be perfectly certain that half of all the atoms will have shot out one within seventeen hundred years. That is an odd fact, isn't it? If you had an ounce of radium in your hand, and could see every atom in it separately, it would be useless to bet on which atom would go next, but it would be a certainty to bet that half of them would have gone by the year A.D. 3600. There is no way of making a radium atom discharge its helium nucleus and nothing can save half of the atoms from changing within the exact time.

Now what is left after the helium nucleus has gone? A gas, which has been called niton because when it is turned into a liquid it shines brightly. In other words, when an atom of radium explodes it turns into two pieces, each one of which is an atom of a new element, one helium, the other niton.

But niton also is an unsteady element like radium. After a very few days one-half of the atoms of any mass of niton will have changed into yet another substance, half of which in half an hour will once more have changed into yet some-

thing else, and so on until after eight distinct changes (each one caused by the shooting out of either a helium nucleus or an electron), what once was radium has become, of all homely and stable things, lead!

And so in a way the alchemists were right, for one element can change into another. But unfortunately in the process one of the most valuable things in the world changes into one of the commonest. And nothing that mankind can do can stop it.

Can we ourselves ever hope to change one element into another? Yes, indeed, it has already been done. Scientists have succeeded in bombarding the atoms of one or two elements in much the same way as we have seen radium bombarding on its own. And from time to time they have scored a direct hit and smashed out a piece of the nucleus of the element and thereby turned each part into an atom of some other element. This is perhaps one of the most exciting adventures to have been successfully undertaken since the war.

The other point that I want to clear up before saying good-bye is the matter of how the ether splashes are made to produce all the different waves we have been meeting. We know that they come from the jumps of the electrons in the atom, but we can say more than that. Dr. Harvey Gibson, whose book, *Two Thousand Years of Science*, you ought to read next if you have found this one interesting, describes what happens to the atom to produce the jumps that make the ether waves. An atom which is quite still has a temperature of —273 degrees centigrade as we have seen; as it gets hotter the molecules are moving around

more and more, but the atoms of which they are composed at first suffer no change.

This movement of the molecules which we studied in the first part of the book is enough to set up the dark heat waves in the ether, but as the temperature rises towards four hundred degrees centigrade, the atoms themselves are disturbed by the terrific rapidity of the motion and the electrons in the outer rings begin jumping. We know of their jumping by the glow of light that begins to come from the substance. The heat increases, and the red glow changes to a white light as more and more electrons are making all the possible jumps in the outer orbits. When six thousand degrees centigrade is reached, that is at the temperature of the surface of the sun, the electrons in the inner rings begin to jump and waves outside the violet light are shot forth. Then as the temperature reaches hundreds of thousands and millions of degrees, as in the centre of the sun, the innermost electrons get agitated and send out X-rays. Hotter and hotter until in the hotter stars at hundreds of millions of degrees the nucleus itself begins to tremble and gamma rays pour forth through space. Lastly, at two million million degrees the protons and electrons inside the nucleus unite and go out in the most violent splash of all and we have the cosmic rays.

And so our detective story, which began with the question, what is the smallest piece of anything like and can we go on cutting a thing in two for ever? has ended in the strangest discovery of a mighty atom, made up of whirling electrons out of which all the world and our bodies are made; a mighty atom full of vast energy which sometimes

shoots itself out into farthest space, splashing the ether to make waves which behave almost exactly like the waves which break at our feet by the seaside. The electron, the proton, and the wave in unknown ether—out of these is everything made. And at present human beings only know the very least part that there is to know about them. There are high peaks to scale, dangerous roads to travel, new worlds to conquer for all who learn to see science as a great adventure, as the greatest of all detective hunts. This book can only hint at some of the adventures waiting for you if you are willing to gather together the right equipment.

And so I wish you good-bye, and if you take up the trail and study the adventure called science—good hunting!